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ON THE RELATIONSHIP BETWEEN THE SPECIFIC GRAVITY AND ASH CONTENTS OF THE COALS OF KOREA AND BOKARO : COALS AS COLLOID SYSTEMS. BY L. LEIGH FERMOR, O.B.E., D.SC., A.R.S.M., M.I.M.M., F.G.S., *Officiating Director, Geological Survey of India.* (With Plates 26 and 27.)

CONTENTS.

I.—INTRODUCTION.

WHEN making an examination of a mineral deposit in order to determine the economic value thereof, one of the most important tasks before the geologist or mining engineer is to take average

samples of the lode or seam at such intervals and over such thicknesses as will enable him both to deduce the average composition of the deposit and to determine which sections of the deposit will repay the cost of working. This, of course, is generally recognised. It is not, perhaps, so generally recognised, however, that very great help is also to be obtained from a chemical study of hand-specimens carefully selected so as to represent the various types of ore, rock, or mineral, building up the mineral deposit.

In the course of my study of the Indian manganese-ore deposits some years ago, I made a careful selection of the various types of ore and had them assayed not only for the constituents usually taken into account in the valuation of manganese-ores, namely, manganese, iron, silica, phosphorus, and moisture, but in addition I was fortunately able to have some of them subjected to complete analysis. Half of each specimen was used for the analysis after the determination of its specific gravity, and the other half was retained for reference. By a comparison of the analysis of a specimen with its appearance, it was possible to work out the quantitative mineral composition of each specimen, and thus to obtain data for an intelligent understanding of the composition of the ore-body as a whole.

On visiting a new manganese-ore deposit it is usually found to be composed of some few of the types of ore already analysed, and it is then simple, by forming a rough estimate of the proportions in which these types are present in the ore-body, and by using one's knowledge of the composition of each type, to form a very fair estimate of the quality of the deposit in advance of the receipt of the results of assays of average samples of the ore, which can as a rule come to hand only after one has left the deposit in question.

On account of the valuable results thus obtained, I was lead to apply similar methods to the study of the Korea coalfields in 1913, and of the Bokaro coalfield in 1916-17. As I have now accumulated a considerable number of analyses of hand-specimens of coal from these two areas and as the study of the Korea data led to the discovery of a rough relationship between the specific gravity of a piece of coal and its ash contents, which was confirmed by data for the Bokaro coalfield subsequently obtained, and as a knowledge of this relationship will enable one to determine the ash contents of a piece of coal in the field usually within four units of the correct figure, and often very much closer, merely by a specific gravity

determination with a Walker's balance, it is, I think, desirable to detail my results for the benefit of the mining community[1].

II.—THE COALS OF THE KURASIA COALFIELD, KOREA STATE.

In my paper 'On the Geology and Coal Resources of Korea State, Central Provinces' published in 1914[2], I have given on p. 182 a table of analyses of 7 hand-specimens of coal from various seams (Barakar series) in the Kurasia coalfield in this State. Each specimen was broken into two roughly equal portions and the specific gravity determination was made in each case on the piece of coal that was actually powdered up for analysis, the other piece of each specimen being kept for future reference. The most interesting type thus examined is the bright coal occurring in layers in the banded coal. This bright coal breaks easily into polyhedral fragments with conchoidal fracture surfaces, and has all the appearance of being a colloid substance and the purest type of coal. As will be seen from the analysis of D. 183 below, this bright coal proves to be nearly pure coal with only 0·51 per cent. ash and a specific gravity of 1·30. Assuming that the specific gravity of theoretically pure coal from Kurasia with no ash would be 1·29, I noticed that if this figure were deducted from the specific gravity of each

[1] That the specific gravity of coal increases with the ash percentage is, of course, a well-known fact, and there have, of course, been other researches in which some co-relation between analysis and specific gravity has been noted, at least implicitly, by the publication of tables of analyses of coals with corresponding specific gravity determinations. The following papers may be cited :—

M. L. Nebel, 'Specific Gravity Studies in Coal', University of Illinois, Bull. No. 89; abstract in *Colliery Guardian*, CXIII, pp. 33-34, (1917).

M. W. Blyth & L. T. O'Shea, 'The Examination of Coal in Relation to Coal-washing', *Trans. Inst. Min. Eng.*, LVII, p. 267, (1919).

T. Fraser and H. F. Yancey, 'Cleaning Tests of Central Illinois Coal', Tech. Paper 361, Bureau of Mines, Washington, pp. 9-13, (1925).

W. Randall, 'Froth Flotation of Indian Coals', *Rec., Geol. Surv. Ind.*, LVI, p. 223, (1925).

Draper and Evans, quoted by J. Coggin Brown in 'Indian Coal Problems', *Bull. Ind. Industries & Labour*, No. 36, p. 23, (1927).

Such investigations have, however, usually been carried out in relation to problems of coal beneficiation, and the authors have not detected a relationship such as that noticed in this paper. Blyth and O'Shea, indeed, go so far as to write (*l.c.*, p. 269) :—

"Generally, the specific gravity increases with the ash content, but, as is evident, no definite relation can be established between ash content and specific gravity, as if the increase is due to admixed mineral matter, the resultant specific gravity will depend on the relative specific gravities of the coal substance and mineral matter and on the proportions in which they are mixed."

[2] *Mem. Geol. Surv. Ind.*, XLI, pt. 2.

of the other types of coal, the results multiplied by 100 agreed roughly with the determined ash contents of the specimen. The values for the ash contents that might thus be predicted, as compared with those actually found, are shown below for each of the 7 specimens in question :—

Specific gravity.	Predicted ash contents.	Determined ash contents.
1·30	1	0·51
1·36	7	9·28
1·45	16	16·42
1·52	23	18·51
1·64	35	33·28
1·61	32	34·96
1·47	18	32·06

Except for the 4th and last analyses the figure predicted is in every case within 3 units of the figure obtained by actual determination. But on account of these two discrepancies, especially the last, I refrained from drawing attention to this fact in the memoir in question, as I was on leave in Europe at the time the proofs passed through my hands, and had no opportunity of checking the two apparently anomalous analyses. The work has since been repeated on a portion of the duplicate material in each case and the results indicate that the analytical and the specific gravity figures of these two coals as printed in the memoir cited have been interchanged. The following table repeats here the analyses of the 7 Kurasia coals referred to above, except that the revised figures are given for the specimens K.4 and 'Gorghela N.' respectively. The analyses are here arranged in order of increasing ash contents. It will be noticed that this is almost coincident with the order of increasing specific gravity. In column 9 is shown the figure obtained by subtracting from the specific gravity the ash contents divided by 100, from which, excluding the figures for the specimens from Gorghela N., one obtains an average of 1·28, which may be used as the datum line for ash-free coal from this field. Using this datum line the figures given in column 10 show the ash contents as predicted

from the specific gravity figures. Column 11 shows the error in the prediction in each case, the maximum error except for specimen G. N., being only 3 units. The only case in which prediction of ash contents from a specific gravity determination would have led to serious error is the specimen from Gorghela Nala, for which the ash contents thus predicted would have been 24 per cent. against nearly 31 per cent., an error as it happens in the right direction, as it would have led to the sampling of the Gorghela Nala seam instead of its neglect.

TABLE 1.—*Analyses, specific gravities and descriptions of hand-*

No. of specimen.	Rock register number.	Locality.	Moisture.	Volatile matter.	Fixed carbon.	Ash as determined.	Specific gravity (G).	$G - \frac{ash}{100}$
1	2	3	4	5	6	7	8	9
D. 183 .	26·669	Dankhuri	9·80	29·18	60·51	0·51	1·30	1·29
D. 164 . .	26·649	Kachhan Kundi	4·66	33·64	52·42	9·28	1·36	1·27
K. 3 . .	27·433	Karar Khoh .	6·16	27·70	49·66	16·42	1·45	1·29
K. 4 . .	27·434	Do. .	7·10	30·26	45·87	16·77	1·455	1·27
G. N. . .	27·435	Gorghela Nala	3·47	29·38	36·55	30·60	1·52	1·21
D. 154 . .	26·639	Karar Khoh	4·10	19·10	43·52	33·28	1·64	1·31
K. 2 . .	27·432	Do. .	3·80	22·28	38·96	34·96	1·61	1·26

specimens of coals from the Kurasia coalfield, Korea State.

Predicted ash contents (G-1.28) × 100.	Error of prediction (10—7) or deviation from standard (1.28).	Caking properties.	Colour of ash.	Description of specimens.	Classification.
10	11	12	13	14	15
2	+1	Sinters slightly .	Buff .	Bright coal layers	First class coals.
8	—1	Does not cake	White . .	Dull slightly silky coal.	
17	+1	Ditto . .	Light brown .	Dull .	Second class coals.
15½	1	Does not cake, but sinters slightly.	Very light grey	Typical dull shale-coal.	
24	—7	Does not cake .	Light brown .	Finely banded bright & dull coal.	Third-class coals.
30	+3	Ditto . .	Brown . .	Greasy lustred shale-coal.	Fourth-class coals.
33	—2	Ditto .	Very light brown.	Greasy lustred shale-coal.	

III.—THE COALS AND CARBONIFEROUS SHALES OF THE BOKARO COALFIELD.

On commencing work in the Bokaro coalfield at the beginning of 1916, I took an early opportunity to send typical specimens of coal to the Geological Survey laboratory in Calcutta for the determination of the specific gravity and proximate chemical composition, the whole of the material upon which the specific gravity was determined being used for analysis. This work was continued during the following field season of 1916-17. These results were required primarily to help the field work in the manner already explained: but, in addition, it was my purpose to ascertain whether in the case of the Bokaro coals a relationship between specific gravity and ash contents could be detected similar to that found to hold for the Korea coals. As a result it was found that the relationship did, in most cases, hold, and in 1919, additional specimens were selected from my collection to fill up gaps in the sequence. Specific gravity determinations and analyses were repeated on duplicate material in some cases where the results seemed to depart seriously from what might be expected. The description of each specimen was recorded before sacrificing it for analysis, and duplicate specimens were as before retained for reference.[1] The full data including the descriptions are assembled in table 2 in order of increasing ash contents. All the specimens come from the Barakar stage of the Gondwana formation and are, therefore, of Palaeozoic age.

On scanning this table it will be observed that on the whole the specific gravity increases *pari passu* with the ash contents, although there are certain marked exceptions [F. 141, F. 112, F. 175 (one analysis)] that interrupt this orderly sequence, F. 141 having a specific gravity that is too high and F. 112 and F. 175 specific gravities that are too low for their place in the sequence. F. 378, F. 142 and F. 138 have also slightly high specific gravities for their position. In column 9 of the table are shown the figures obtained by subtracting from G, the specific gravity, the ash contents divided by 100; in other words, the figures in column 9

$$= G - \frac{\text{ash contents}}{100}$$

[1] The analyses and specific gravity determinations of the Korea specimens were made by Mahadeo Ram, and of the Bokaro specimens mainly by Mahadeo Ram and Baroda Charan Gupta.

TABLE 2.

Analyses, specific gravities, and descriptions, of hand-specimens of coal and carbonaceous shales from the Bokaro Coalfield.

TABLE 2.—*Analyses, specific gravities, and descriptions, of hand-specimens*

1	2	3	4	5	6	7	8	9	10
Field number of specimen.	Rock register number.	Locality.	Moisture.	Volatile matter	Fixed carbon.	Ash.	Specific gravity (G)	$G - \frac{ash}{100}$	Deviation from standard (1·26)
F. 377* .	23·996	Seam 13, Joint Railway colliery.	1·99	27·47	68·23	2·31	1·28	1·26	0
F. 377† .	23·996	Ditto . .	1·21	27·76	68·53	2·50	1·28	1·255	0
F. 114* .	23·926	Seam 13, Sawang . .	2·24	29·83	64·32	3·61	1·30	1·26	0
F. 116* .	23·928	Ditto . .	1·53	29·72	61·50	7·25	1·33	1·26	0
F. 378* .	23·997	Seam 1, Jharna Nala .	0·71	18·84	71·99	8·46	1·38	1·30	+4
F. 379* .	23·997	Seam 7, Ditto .	1·12	22·69	62·80	13·39	1·39	1·26	0
F. 109* .	23·921	Seam 13 (pit), Sawang .	1·00	29·74	55·40	13·86	1·41	1·27	+1
F. 109‡ .	23·921	Ditto .	1·16	26·82	53·60	18·42	1·42	1·24	-2
F. 109* .	23·921	Ditto .	1·30	24·56	52·35	21·79	1·48	1·26	0
F. 169† .		Seam 8, Gobindpur	0·40	19·98	57·44	22·18	1·51	1·29	+3
F. 111‡ .	23·915	Seam 9, Sasbehra Garha (trench).	0·60	20·57	51·38	21·45	1·58	1·34	+8
F. 141* .	23·915	Ditto . .	1·19	20·66	52·27	25·88	1·63	1·37	+11
F. 168† .	—	Seam 8, Gobindpur .	0·50	21·41	51·23	26·86	1·53	1·26	0
F. 112* .	23·924	Seam 13, Sawang . .	1·60	25·83	44·96	27·61	1·49	1·21	−5
F. 159*a*†	23·951	Trench, tributory of Sasbehra Garha.	0·18	22·61	49·17	27·74	1·54	1·26	0
F. 141† .	23·945	Seam 9, Sasbehra Garha (trench)	0·43	24·61	45·81	29·15	1·63	1·34	+8
F. 142† .	23·946	Ditto . .	0·48	21·00	48·05	30·47	1·60	1·30	+4
F. 139† .	23·943	Seam 9, Sawang (pit 3) .	0·57	20·67	45·83	32·93	1·59	1·26	0
F. 138† .	23·942	Ditto . .	0·57	17·41	25·91	36·11	1·66	1·30	+4
F. 175* .	23·966	Seam 15, Sawang (D. B. H. V.)	0·98	22·05	37·60	39·37	1·65	1·26	0
F. 175† .	23·966	Ditto . .	0·86	22·69	32·89	43·56	1·57	1·13	−13
F. 167† .	23·962	Seam 8, Gobindpur .	0·40	16·29	38·79	44·52	1·72	1·27	+1
F. 140† .	23·944	Seam 9, Sawang (pit 3) .	0·58	19·18	31·24	49·00	1·77	1·28	+2
F. 364* .	23·981	Jharna Nala . .	1·47	16·93	27·20	54·40	1·86	1·32	+6
F. 175* .	23·966	Seam 15, Sawang (D. B. H. V.)	1·76	15·86	26·03	56·35	1·86	1·30	+4
F. 111* .	23·923	Seam 13, Sawang (pit 1)	1·57	17·31	19·17	61·95	1·98	1·36	+10
F. 181* .	23·972	Godo Nala, Bermo .	1·08	12·11	20·19	66·62	2·01	1·34	+8
F. 181† .	23·972	Ditto . .	0·91	9·92	20·64	68·53	2·03	1·34	+8
F. 64§ .	—	Moutiko Nala . .	0·85	7·87	17·32	74·12	2·19	1·45	+19
F. 170† .	23·963	Seam 8, Gobindpur .	0·51	11·57	0·51	87·41	2·58	1·71	+45

NOTES.—1. These analyses were made by Mahadeo Ram (*), Baroda Charan Gupta (†), Bengal Iron
In cases where the data were

2. All these localities are in East Bokaro (the section of the field east of Lugu Hill), except those of
been correlated with those of East Bokaro. Seam 13 in East Bokaro is the well-known Kargali

of coal and carbonaceous shales from the Bokaro coalfield.

11	12	13	14
Caking properties.	Colour of ash.	Description of specimens.	Classification
Cakes strongly	Yellow	Bright coal substance with few minute dull laminae.	
Ditto	White	Ditto	
Ditto	Do.	Bright coal substance	
Ditto	Do.	Silky coal with bright bands	First-class coals
Cakes	Do.	Ditto	
Cakes strongly	Do.	Silky coal with numerous thin bright bands	
——	——	Silky coal with some bright bands	
Cakes strongly	Brownish white	Silky coal with some bright bands	
Cakes, but not strongly.	White	Ditto with bright bands removed	Second-class coals
Cakes	——	Satiny coal with bright laminae and veinlets	
——	——	Granular, banded, semibright coal	
Does not cake	Dark reddish brown	Ditto	
Cakes	——	Stone coal, finely laminated bright and dull	
Cakes strongly	Buffish white	Shaly coal (banded bright and dull)	Third-class coals
Do. feebly	——	Laminated satiny coal	
Cakes	Dark grey	Granular, banded, semi-bright coal	
Do.	Grey	Finely laminated dull and bright	
Do.	Do.	Black silky coal with fine lamination	
Do.	Do.	Dull silky grey coal with bright veinlets	
Cakes strongly	Greyish white	Dull greasy-lustred coal approaching shale	
Cakes	——	Ditto	Fourth-class coals.
Do.	——	Dull grey coal with thin bright bands	
Do.	Light grey	Laminated dull coal with bright streaks	
Does not cake	Light buff	Carbonaceous shale	
Ditto	Light yellow	——	Coaly shales and carbonaceous shales.
Ditto	White	Shaly coal (or carbonaceous shale with thin bands of bright coal)	
Ditto	Very light yellow	Coaly m. c. shale	
Ditto	——	Ditto	M. c. shales (micaceous carbonaceous shales).
——	——	Micaceous carbonaceous shale (M.c. shale)	
——	——	Ditto ditto	

Co. (‡) and C. S. Fawcitt (§). Specific gravity determinations by the analysts. Blanks are shown in columns 11 and 12 not recorded by the analysts.
F. 378, F. 379, and F. 381, Jharna Nala, which is in West Bokaro. The numbers of the West Bokaro seams have not seam.

Considering for the present only those analyses showing less than 50 per cent. of ash, that is those that can properly be called coals (see column 14 of the table), we find that for 17 specimens, each represented by 1 or more analyses, in no less than 9 cases does this figure come to 1·26. The difference in each case of the figure so obtained from 1·26 is shown in column 10 of table 2, each unit representing 0·01. These *deviations*, as I propose to call them, may be summarised as follows:—

Amount of deviation (unit 0·01)	No. of cases
−13	1
−5	1
−2	1
0	10
+1	2
+2	1
+3	1
+4	3
+8	2
+11	1

1·26 is therefore adopted as the *fundamental specific gravity of pure ash-free Bokaro coal* and the deviations from this figure ranging from −2 to +4 above are not thought to need any particular explanation. But some explanation of the two low specific gravities and the three high ones appears desirable.

My first thought was that there might be some inherent difference between the carbonaceous material of these exceptional coals and that of coals of more normal density. First, however, I had F. 175 re-analysed, as an example of unusually low density (−13), and F. 141 as an example of unusually high density (+8). F. 175, on re-analysis, gave the upper of the two analyses shown in table 2 and the correspondence here for ash and density is so good that $G - \frac{\text{ash}}{100} = 1 \cdot 26$; so that we are compelled to assume that there is some error in the first determination either in the analysis or in specific gravity. The other low example (−5) has not been retested. A possible explanation of this deviation is given on page 334.

Coming now to the high figures, F. 141 with a deviation of +8 was re-analysed and found to give a deviation of +11, so that evidently this high figure is not due to any error, but is particular to this coal.

Dr. Fox suggested to me that the departure of some of these coals from my rule might be due not so much to differences in the character of the carbonaceous substance as in the composition of the ash. To test this I selected three specimens, namely, one Korea coal conforming to rule (K.3 ; −1), one Bokaro coal conforming to rule (F.109 ; 0 and +2), and the high gravity Bokaro coal (F. 141 ; +8 and +11). At Dr. Fox's request, Mr. Dawes Robinson, Chief Chemist to the Bengal Iron Co., Ld., very kindly had the ash of these three specimens analysed in his laboratory. The results are as follows :—

TABLE 3.—*Analyses of ash of coals from Korea and Bokaro.*

Coalfield.	Kurasia field, Korea.	Bokaro.	
Number of specimen.	K 3 : 27/133.	F.109 : 23 921	F.141 : 23 945
Specific gravity (G) . . .	1·428	1·409	1·585
Proximate analysis :			
Moisture	4·80	1·00	0·60
Volatile matter	27·09	29·74	20·57
Fixed carbon	52·40	55·40	54·38
Ash	15·71	13·86	24·45
	100·00	100·00	100·00
Analysis of ash :			
SiO_2	61·20	52·10	32·60
Al_2O_3	32·19	41·09	42·35
Fe_2O_3	3·71	3·71	16·86
CaO	0·40	1·60	4·20
MgO	2·37	0·79	2·37
SO_3	0·09	0·09	0·08
P_2O_5	0·09	0·09	1·59
	100·05	99·77	100·05
$G - \frac{ash}{100}$	1·27	1·27	1·34
Deviation from standard* . .	−1	+1	+8

* 1·28 for Korea, 1·26 for Bokaro.

From these analyses it will be seen that the first two are normal coals with specific gravity conforming closely to the rule, but that the third analysis with a deviation from the standard of +8 confirms the two previous analyses of F. 141. The reason is seen to lie, as Dr. Fox suggested, in the different compositions of the ash. K. 3 and F. 109 have identical ferric oxide (3·71 per cent.) and nearly identical total silica plus alumina (93 per cent.). F. 141, the abnormal coal, has nearly 17 per cent. of ferric oxide and only 75 per cent. of silica plus alumina. We see now that F. 141 owes its high specific gravity to unusually high contents of iron oxide—amounting to over 4 per cent. of the weight of the coal.

We may, I think, legitimately deduce from these figures that the rule we have discovered connecting specific gravity and ash contents of Korea and Bokaro coals applies particularly to cases where the ash content is mainly comprised of silica and alumina (in fact dehydrated clay) with only low iron contents, and that a high density relative to that required by our rule indicates an ash of higher density than usual, no doubt almost always due to the presence of a compound of iron, which I have, indeed seen on several occasions as red spots of hematite in certain Bokaro coals.

We have now explained the three high positive figures above the 50 % ash line in table 2: the colour of the ash recorded in two cases dark reddish brown and dark grey (? reducing atmosphere) may be taken as concordant. If the smaller figures of +4 recorded in three cases are due to a small excess of iron oxide the amount does not appear to have been enough to affect the recorded colour of the ash.

The seriously large negative figure (−13) has been explained as probably due to an error and we can therefore confidently adopt our rule for future use.

The rule is that for Korea and Bokaro coals (Barakar series) there is a definite numerical relationship between ash contents and specific gravity. If g denote the specific gravity of the coal, a the ash contents, and k the specific gravity constant of pure coal, then

$$g - \frac{a}{100} = k,$$

$$\text{or } a = 100\,(g - k).$$

For Korea coals $k = 1{\cdot}28$; for Bokaro coals $k = 1{\cdot}26$. For each field k should be separately determined, but in cases where this

has not been done it would perhaps be better to use the Bokaro constant, because it is based on a much larger number of analyses than the Korea constant.[1]

The constant can, however, be determined quickly and directly by picking out as pure a specimen of bright coal as possible, and sending it to a laboratory for proximate assay and specific gravity determination on the same material.

In Plate 26 both the Korea and Bokaro results are plotted to scale, with specific gravities as ordinates and ash contents as abcissæ, the points representing the Korea data being distinguished by circles. Discussing only the Bokaro data and confining ourselves as hitherto to coals (up to 50 per cent. of ash) we see that the majority of the results conform quite closely to a straight line law with origin at 1·26. The three points that lie some distance above this line (ash 24 to 29 per cent.) represent the three analyses of the high iron coal F. 141. The one spot rather far below is the

[1] That the values of this constant adopted for Korea and Bokaro coals respectively differ may be due to the fact that the Korea figure is based on only 7 analyses. But consideration of the Korea data given in table 1 makes one prefer to adopt the view that the difference actually exists. The curious point then is that the coals with the higher moisture, namely those of Korea, have the higher fundamental specific gravity instead of the smaller. This suggests a parallel relationship between moisture contents and specific gravity, a suggestion that receives support from data representing two specimens of coal collected by me in the Island of Skye some years ago. The proximate analyses and specific gravities are given in the following paper (p. 359), from which it will be seen that with moisture contents still higher than that of the Korea coals, the Skye coals give also a higher specific gravity constant for pure coal, namely 1·30 and 1·32, or a mean of 1·31. It is true that the colour of the ash is recorded as light brown and brown respectively, but the total percentage of ash is small, and calculation shews that using the ash percentage and specific gravity figures actually determined the values of k calculated from the first coal are 1·313 and 1·303 according as the specific gravity of the ash contents be taken as 3·0 and 5·0. The facts for the three sets of coals may be summarised as follows: –

Locality.	Number of analyses.	Moisture.		Specific gravity constant (k).
		Range.	Average.	
Bokaro	23	0·40— 2·24	0·95	1·26
Korea	7	3·47— 9·80	5·58	1·28
Skye	2	11·41– 11·72	11·56	1·31

The significance of this parallel relationship is discussed in Section VIII of this paper.

—5 coal F. 112. The Korea coals are also sufficiently close to the upper straight line with origin at 1·28 except the —7 coal No. G.N.

We may say then that for coals (as distinct from carbonaceous shales) the diagram shows that for all practical purposes we may accept a straight-line law for the relationship between ash contents and specific gravity as is required by the formula already empirically deduced above.

Let us return now to our table No. 2 and consider the analyses corresponding to carbonaceous substances with more than 50 per cent. of ash—carbonaceous shales of various sorts in fact. From column 9 it will be seen that they invariably show a positive deviation from the standard specific gravity when treated according to the rule, and that on the average this deviation increases rapidly with increasing ash contents so that with 66 per cent. of ash it is +8, with 71 per cent. it is +19 and with 87 per cent. it is +45. The beginning of this deviation was perhaps indicated by the last two coals with deviations of +1 and +2 respectively, but these deviations may be only conformable in significance with those shown higher up on the list of coals. On referring again to our diagram it will be seen that on plotting these density-ash values for the carbonaceous shales we find that the curve is no longer a straight line.

If we assume that the last determined point on our curve, with $G = 2·58$, 87·1 per cent. of ash and 12·6 per cent. of total volatiles, is a simple mixture of shale of $G = x$ and coal substance of $G = 1·26$, then we find that the specific gravity of the shale portion is 3·01. This is, of course, a high figure for shale, but it gives us a maximum point for the termination of our curve on the ordinate corresponding to 100 per cent. of ash.

IV.—EXPLANATION OF THE EMPIRICAL DENSITY-ASH RULE.

It appears then that we have discovered an empirical rule connecting the specific gravity of coal and its ash contents that applies closely to coals containing up to 50 per cent. of ash, but which does not apply to the carbonaceous substances containing over 50 per cent. of ash, *i.e.*, to carbonaceous shales. It is desirable, if possible, to discover the reason for this empirical rule and its limitations, and also what is the theoretical rule.

Let us investigate the case of a series of mixtures of pure coal of specific gravity k (our constant) with a non-carbonaceous diluent,

which we may regard as shale of specific gravity s. As before, g stands for the specific gravity of the impure coal or carbonaceous shale and a for the percentage of ash or shale in the coal or carbonaceous shale. It is evident that

$$\frac{a}{s} + \frac{100-a}{k} = \frac{100}{g}, \qquad (1)$$

from which we find that

$$s = \frac{akg}{ag-100\,(g-k)}. \qquad (2)$$

We can now consider three cases. The first is that in which our empirical rule

$$a = 100\,(g-k) \qquad (3)$$

is assumed to hold for the whole range from 0 to 100 per cent. of ash or shale. Substituting this value of a in equation (2), we find that

$$s = \frac{kg}{g-1} \qquad (4)$$

The following table shows the values of g and s for each 10 per cent. of ash from 0 to 100:—

a	g	s	a	g	s
0	1·26	6·11	50	1·76	2·92
5	1·31	5·33	60	1·86	2·73
10	1·36	4·76	70	1·96	2·57
20	1·46	4·00	80	2·06	2·45
30	1·56	3·51	90	2·16	2·35
40	1·66	3·17	100	2·26	2·26

It is obvious that the specific gravity of the diluent 'ash' cannot vary continuously (from 6·11 to 2·26) with the percentage present. Nevertheless the relation

$$a = 100\,(g-k)$$

is found empirically to hold over the range of ash contents from 0 to 50 per cent., as if, therefore, the density of the ash does range from 6·11 to 2·92. The figures in the above table have, therefore, been plotted as the curve CE in Plate 27. We shall see later what significance they have.

The second case is that in which our empirical rule (3) is still assumed to hold for the whole range from 0 to 100 per cent. of ash or shale, but in which we allot a constant value to the specific gravity s of the ash or shale, and investigate what variations in the specific gravity of the organic matter are necessary to give the linear rule. Taking v as the specific gravity of the organic matter (vitrain[1] + vegetable detritus) and substituting it for k in equation (1), we find that

$$v = (100-a) \times \frac{gs}{100\,s - ag},$$

and substituting the value of a according to equation (3),

$$v = \frac{gs\,[1-(g-k)]}{s-g\,(g-k)}$$

The following table shows the value of g and v for each 10 per cent. of ash from 0 to 100 (1) if $s = 2 \cdot 6$, and (2) if $s = 3 \cdot 0$:—

$s = 2 \cdot 6$			$s = 3$		
a	g	v	a	g	v
0	1·26	1·26	0	1·26	1·26
5	1·31	1·277	5	1·31	1·272
10	1·36	1·292	10	1·36	1·282
20	1·46	1·316	20	1·46	1·294
30	1·56	1·332	30	1·56	1·294
40	1·66	1·338	40	1·66	1·279
50	1·76	1·330	50	1·76	1·245
60	1·86	1·304	60	1·86	1·185
70	1·96	1·245	70	1·96	1·083
80	2·06	1·125	80	2·06	0·914
90	2·16	0·856	90	2·16	0·614
95	2·21	0·574	95	2·21	0·368
100	2·26	0	100	2·26	0

Taking $s = 3$, the corresponding values of v have been plotted as the curve AK in Plate 27. As the linear rule holds only over the range of ash contents from 0 to 50 per cent., we are concerned only with the range of density of the organic matter from 1·26 through 1·294 to 1·245. If the organic matter could be regarded as composed of vitrain only, we could hold, as with the ash, that the specific gravity of the vitrain could not vary continuously with the percentage present. But the organic part of this coal probably contains two types of substances, namely, vitrain and vegetable detritus

[1] See Section VI, page 336.

(see p. 314), and if the latter had a higher specific gravity than the vitrain, then the specific gravity of the two should increase with increase in the percentage of vegetable detritus. This assumption would not, however, explain the subsequent decrease in specific gravity, and consequently again it seems necessary to deduce that the specific gravity of the organic portion of the coal does not change continuously with the percentage thereof present.

The third case is that in which we assume that the various coals and carbonaceous shales may be regarded as mechanical mixtures of pure coal of specific gravity k and shale of specific gravity s. From equation (1) it is evident that

$$g = \frac{100}{\frac{a}{s} + \frac{100-a}{k}} \qquad (5)$$

Assuming various values for s, the specific gravity of the admixed ash or shale, we can calculate the specific gravities of coals and carbonaceous shales ranging from 0 to 100 per cent. of ash or shale, and compare the results with those required by the empirical rule and with those actually determined by experiment. These values have been calculated for the values of s from 2·6 to 3·1. It is unnecessary to print them here, but the deviations of the figures so calculated from the specific gravity figures required by the empirical rule are shown in table 4 on the next page.

We have to decide which of these calculated sets of deviations agrees best with the facts. Our curve OB in Plate 26 expresses the smoothed results of experiment, and from this have been taken the figures given in column 8 of our table 4.

On comparing the deviations given in column 8 with the deviations for various assumed specific gravities of admixed ash or shale, we observe that the closest agreement is with the deviations for $s = 3·0$. This we might have anticipated, as our curve OB in Plate 26 terminates at about 3·04 for 100 per cent. of ash. 3·0 is a high figure for the specific gravity of ordinary shale, but it is that which suits best our data. In Plate 27, I have, therefore, inserted the curve AF showing the specific gravities for admixtures of pure coal of $k = 1·26$ and pure ash or shale of $s = 3·0$. It will be seen from the diagram that this curve AF cuts the curve AE representing our empirical rule at H corresponding to about 45 per cent. of ash. There is not room to re-plot on this figure the curve OB of Plate 26

TABLE 4.—*Deviations of calculated specific gravities of coal and carbonaceous shales, with different assumed specific gravities of admixed ash or shale, from specific gravities required by the empirical straight-line rule.*

Percentage of ash.	Assumed specific gravity of ash or shale.						Deviations measured from curve O B in figure 1.
	2·6	2·7	2·8	2·9	3·0	3·1	
0 . .	0	0	0	0	0	0	0
5 . .	2	-1½	1½	-1	-1	-1	0
10 . .	-3	[illegible]	3	--2½	-2	2	0
20 . .	5½	5	1½	—1	-3½	--3	0 (-2)
30 . .	7	6	[illegible]	--4	3	-3	0 (-5)
40 . .	-7	5	1	--3	-2	—1	0
50 . .	6	1	2	0	+2	+3	+2
60 . .	-1	-1	+2	+5	+7	+10	+6
70 . .	+1	+6	+9	+13	+16	+19	+13
80 . .	+3	+13	+19	+24	+29	+34	+29
90 . .	+19	+26	+34	+41	+48	+55	+50
100 . .	+34	+44	+54	+61	+74	+84	+78

NOTE.—Units of deviation represent 0·01.

representing the experimental facts. But if so plotted it would coincide throughout neither with the theoretical curve AF (based on s = 3·0) nor the empirical curve AE. Above 45 per cent. of

ash it would, it is true, coincide almost exactly with the portion HF of the curve AF, but below 45 per cent. it would coincide with the portion AH of the curve AE.

The agreement of facts with the curve AF above 45 per cent. of ash indicates that above this point we are dealing with mechanical mixtures of coaly matter and shale. One would have expected, therefore, that the data would continue to agree with the curve AF below 45 per cent. The fact that in the majority of cases they do not must have some significance. One possibility is that below 45 per cent. of ash the specific gravity of the ash conforms to the curve CE. This seems inherently improbable, especially in view of the ash compositions given in table 3. We must accept the likelihood, therefore, that the specific gravity of the ash of coals with less than 45 per cent. of ash is not in normal cases higher than that of coals and carbonaceous shales above 45 per cent. of ash. Another possibility, namely that the specific gravity of the organic portion of the coal might vary according to the curve AK, has already been rejected. Our facts appear then to prove that the ash contents of coals with less than 45 per cent. of ash is not present, at least entirely, in mechanical admixture with the carbonaceous matter: instead they appear to prove that *the association of carbonaceous matter and inorganic matter is accompanied by decrease of volume, suggesting that at least a portion of the ash contents of such coals is in chemical or physical association with the carbonaceous matter.* In section VIII of this paper it is suggested that the data are explained adequately by the assumption that the particular form of association is colloidal; decrease of volume is a characteristic of many colloidal systems.

V.—SIGNIFICANCE OF THE EMPIRICAL RULE: CONTAINED INORGANIC MATTER PARTLY IN CHEMICAL OR PHYSICAL ASSOCIATION WITH THE COAL.

It is not possible from this statistical investigation to show whether the whole of such inorganic matter is in such colloidal association, or only a portion. But the space between the two curves AF and AE between the points A and H is a measure of the condensation that has accompanied the admixture or association of carbonaceous matter and inorganic matter, and if with the lower-ash coals all the inorganic matter is in colloidal asso-

ciation with the organic matter, it seems likely that with the decreasing total condensation indicated for ash contents in excess of 30 per cent. ($s = 3{\cdot}0$) to 40 per cent. ($s = 2{\cdot}6$), the proportion of inorganic matter in colloidal association with organic matter progressively decreases.[1] If it be objected that the specific gravity of admixed shale upon which the curve AF is based, namely 3·0, is too high for normal shale, the answer is that if a lower figure be selected, say 2·6, the space separating the two curves AF and AE between the points A and H becomes wider, indicating a still greater degree of condensation.

Attention may now be redirected to the two analyses (F. 109 and F. 112) in table 2 showing minus deviations from the rule. These deviations have been inserted in brackets in column 8 of table 4. It will be seen that they occur at points corresponding roughly with the maximum minus deviations for calculated mixtures. These analyses have not been repeated; but it seems possible that such deviations may not be errors, but may indicate instead coals in which admixture of carbonaceous and inorganic matter has not been accompanied by reduction of volume. The —7 Korea coal with 30·60 per cent. of ash may also be cited.

From Plate 27 we see that even if our coals conformed to the curve AF below the point H as well as above it, their density-ash relationships would be sufficiently close to those pertaining to our empirical rule for the latter to be of practical value for coals as distinct from carbonaceous shales. Actually we see that the empirical rule appears to be the closer to the truth for the range 0 to 45 per cent. of ash, indicating the colloidal association between the carbonaceous and inorganic matter discussed in Section VIII.

In my memoir on the coal deposits of Korea, I suggested that[2]

'The *bright coal* is the purest, and, judging from its brilliant conchoidal fracture, is of the nature of a colloidal[3] substance which has in some way segregated chemically from the admixed earthy materials that give rise to the greater proportion of the ash of the coal.'

[1] In other terminology, we may be approaching the concentration limit of ash as the disperse phase.

[2] *Mem. G.S.I.*, XLI, p. 180, (1914).

[3] This was not, I find, the first suggestion of the colloidal nature of the bright coal substance. H. Potonié noted the colloidal nature of humus in his work 'Die rezenten Kausto-biolithe u. ihre Lagerstätten', *Abhandl. d. K. Preuss. Geol. Landesanstalt*, Neue Folge. Heft 55, II, p. 3, (1911).

Stopes and Wheeler in their paper on the 'Constitution of Coal', Depart. of Scientific & Industrial Research, p. 19, (1918), mention H. Winter as believing in the colloidal nature of coal, quoting *Glückauf*. Vol. 49, pp. 1406-1413, (1913).

The view that this bright coal is a colloidal substance seems now to be meeting with general acceptance[1] and many close observers of coal must be prepared to accept the idea that such coal has clarified itself by chemical segregation. In the same memoir (*l.c.*, p. 187) I give a case of the formation within bright layers of coal of concretionary segregations of lithomarge, and hail these as giving force to the view that the bright coal has been formed by colloidal segregation. This observation concerning lithomarge is of special interest to us now as showing that during the formation of coal, mineral matter may itself be in a state of sufficiently fine subdivision[2] to enable it—in cases where it does not segregate from the carbonaceous matter as in the Korea case just cited[3]—to enter into the intimate chemical (or physical) association with organic matter that seems to be indicated by Plate 27.

If we accept the probability that the inorganic matter in coals and carbonaceous shales may be partly present in colloidal association with carbonaceous matter and partly in mechanical admixture, then we appear to arrive at the important conclusion illustrated in Plate 27 that in coals with ash percentages of 0 to 45 colloidal association between the carbonaceous matter and the inorganic matter plays a significant part, whilst for carbonaceous shales above 50 per cent. of ash mechanical admixture predominates and colloidal association of organic and inorganic matter, if it occurs at all, is not of importance.

A reference to table 4 will show that had our curve AF in Plate 27 been based on $s = 2{\cdot}9$, which agrees nearly as closely with our experimental facts as $s = 3{\cdot}0$, the curves AF and AE would have crossed at 50 per cent. of ash. It appears, therefore, that in selecting 50 per cent. of ash as the dividing point between coal and shale (see p. 328 and diagram, Plate 26) we have selected on arithmetical grounds a point which agrees closely with that marking a significant difference between most coals and most carbonaceous shales, namely colloidal association of organic and inorganic matter in the one case and mechanical admixture thereof in the other.

[1] See, *e.g.*, R. H. Bogue, 'The Theory and Application of Colloidal Behaviour', Vol. II, p. 511, (1924).

[2] On high degree of dispersity in the terminology of colloid chemistry

[3] And is not already in chemical combination with residual plant tissues.

VI.—NOMENCLATURE OF COALS.

In column 13 of table 2, I have entered the descriptive name attached to each specimen at the time of collection, when it was examined in the freshly fractured condition in bright sunlight. It will be seen that a great variety of descriptive terms were used. A comparative examination of all these specimens shows that they can be arranged into the groups shown in the following table :—

TABLE 5.- *Grouping of Bokaro coals according to appearance, ash contents and specific gravity deviations.*

——	Field number.	Rock register number.	Ash contents.	Specific gravity deviation.	Interpretation.
I. Bright coal substance	F. 377	23 906	2·31	0	Vitrain.
	F. 377	23 906	2·50	0	
	F. 114	23 920	3·61	0	
II. Silky coal with bands of bright coal, grading into dull greasy-lustred coal without bright coal.	F. 116	23 928	7·25	0	Silky coals (durain) with macroscopically visible vitrain.
	F. 370	23 997	13·39	0	
	F. 109	23·921	13·86	+1	
	F. 109	23 921	18·42	—2	
	F. 109	23 921	21·79	0	
	F. 159	23 954	27·71	0	
	F. 130	23 043	32·03	0	
	F. 138	23·942	36·11	+4	Dull silky coal (durain) with some vitrain.
	F. 175	23 966	39·11	0	Dull greasy-lustred coal (durain).
	F. 175	23 966	56·35	+4	
III. Granular coal	F. 141	23 945	24·45	+8	Ferruginous coal of durain with vitrain.
	F. 141	23 945	25·88	+11	
	F. 141	23 945	29·15	+8	
IV. Shaly coal grading into coaly shale.	F. 112	23 924	27·61	—5	Interbanded vitrain and carbonaceous shale.
	F. 142	23 946	30·47	+4	
	F. 167	23 962	44·52	+1	
	F. 140	23·944	49·00	+2	
	F. 111	23·923	61·95	+10	
V. Carbonaceous and m.c. shales.	F. 364	23 984	54·40	+6	Carbonaceous shale (trace of vitrain in F. 181).
	F. 181	23·972	66·62	+8	
	F. 181	23 972	68·53	+8	
	F. 64	—	74·12	+19	
	F. 170	23·963	87·41	+45	

When these specimens were originally described, Dr. Marie Stopes had not proposed her four names for varieties of bituminous coal.[1] I did not myself feel any special need for such a scheme of nomenclature, but I have nevertheless attempted in the final column above to make use of her terms where possible. 'Fusain' or 'mineral charcoal' is sometimes present in films on the bedding planes of the coal, but is unimportant. Clarain I cannot identify in these coals.[2]

Groups I & II.—Bright, silky and greasy-lustred coals.

I have accepted the bright coal substance forming group I above as *vitrain* and specimen F. 175 in group II as *durain*; assuming that these identifications are correct, the remainder of the coals in group I appear to be mixtures of vitrain and durain, the macroscopically visible vitrain becoming less abundant and the durain more abundant as the ash percentage rises. Such vitrain is important in quantity only in the first two specimens. As the percentage of macroscopically visible vitrain falls, the lustre of the durain itself also gradually changes from rather bright silky to dull greasy-lustred, possibly with the decrease of microscopically present vitrain. At the same time the tint of the durain becomes less black and more grey. Thus F. 109 is blacker and more lustrous than

[1] *Proc. Roy. Soc. London*, Ser. B., Vol. XC, pp. 470-486, (1919).

[2] Judging from Dr. Stopes' descriptions, durain and clarain are only mixtures of vitrain and vegetable debris, clarain containing a larger percentage of vitrain than durain, and a smaller percentage of vegetable debris. In addition there is a difference in the character of the admixed vegetable debris, this debris in the durain containing a higher percentage of spores than that in the clarain. It seems, therefore, possible for durain to grade into clarain, the lustre becoming increasingly bright as the percentage of vitrain increases. The lustre of the duller coal separating the vitrain laminae in specimens F. 116 and F. 379 does not however, appear to me bright enough to justify referring this coal to clarain as described by Dr. Stopes. This note is inserted because it seems to me unlikely that I have missed any constituent in the Bokaro coals that occurs in any abundance. Mr. W. Randall, however, in his study of Jharia coals, which are very similar to the Bokaro coals, evidently recognised what he took to be clarain (see *Rec. G.S.I.*, LVI, p. 223). In the table of ash contents given Jharia clarain is shown as containing from 5-15 per cent. of ash and durain as containing 20-40 per cent. of ash; if ash contents and specific gravity were the criteria for distinguishing between clarain and durain, some of the coals in my vitrain-durain series, say F. 116, F. 379 and F. 109, should be termed clarain. That this would be an unsound step is indicated by referring to the table of Korea coals in which coal with as little as 9 per cent. of ash is described as 'dull, silky' and is obviously not bright enough to be termed clarain. See also page 343.

F. 175. F. 109 also shows scattered seams and specks of lustrous vitrain, whilst F. 175 shows none.

Group III.—Granular coals.

The one specimen of this type is composed as before of vitrain and durain in banded association, but breaks with a granular fracture, due perhaps to the method of distribution of the high iron contents revealed by analysis.

Group IV.—Shaly coals.

These consist of alternate bands of the bright coal substance (vitrain) and black carbonaceous shale, the former falling off in quantity as the ash content rises, so that eventually this type becomes a coaly shale. This is the type of coal or shale that forms hard bands in the Kargali coal seam (No. 13) of the Bokaro coalfield.

Group V.—Carbonaceous shales.

These grade from types with lower ash which are dead black (carbonaceous shales) into types that are slightly less black and are harder and show minute micaceous scales on the bedding planes (micaceous carbonaceous shales — *m.c. shale* for short). These shales occasionally show a trace of vitrain and by interbanding with vitrain pass into group IV. A great thickness of m.c. shale occurs a short distance above the Kargali coal seam of Bokaro.

A glance at the deviations of the specimens in these five groups from the specific gravity required by the empirical rule shows at once that they can be arranged into two sections, namely, groups I and II with zero deviations and groups III, IV and V with plus deviations. Thus it is the vitrain-durain series (groups I and II) that conforms to our empirical rule represented by the section AH of our straight line curve in Plate 27 and it is in this series that we must look for our combined or physically associated inorganic matter. Group III shows a plus deviation on account of its high iron (see p. 325). The shales of group V conform to the section HF of the

curve for mechanical mixtures in Plate 27. The shaly coals and coaly shales of group IV being composed of alternations of vitrain with a zero deviation and carbonaceous shale with plus deviations, naturally show a plus deviation also.

In the present paper we are primarily interested in the specific gravity of the pure coal substance of the various coals studied, and it appears from the deviations collected above for groups I & II that it does not matter whether the coal is vitrain, or durain, or mixtures thereof : for the fundamental specific gravity of the carbonaceous matter of all appears to be 1·26 (Bokaro), indicating that if there is any fundamental difference between these two substances, the carbonaceous matter, whether colloidal matrix, spores or woody matter, has, for practical purposes, in most cases the same specific gravity.

A study of this vitrain-durain series shows in fact that for practical purposes the coals of this series from Bokaro may be regarded as formed from the association of two apparently (macroscopically) homogeneous substances in varying proportions. One of these is the bright coal substance (vitrain) represented by specimen F. 377 with only 2·31 per cent. of ash, and the other is the dull greasy-lustred coal represented by specimen F. 175 with 39·37 per cent. of ash. This latter type is the variety termed 'shale-coal' in my Korea memoir, and 'dull greasy-lustred coal approaching shale' in table 2 of this present paper. I quote here the paragraph in my Korea memoir referring to this variety of coal (*l.c.*, p. 181) :

> 'The dull coal tends to possess a shaly structure, and seems to gradate (see analysis of K.3. table 1, for an intermediate stage) into a stony coal-shale or *shale-coal* of very distinctive appearance. This is heavy (G 1·64), with a grey-black colour, almost bluish in the sun, a greasy lustre and a conchoidal fracture; the general appearance is that shown by some varieties of psilomelane. except for the fact that this shale-coal is commonly thickly besprinkled with fragments of carbonised vegetable matter, and that it often shows small stringers and veinlets of bright coal. It tends to fracture into slabby pieces, but the shaly structure is not well developed. I refer to it, however, as shale-coal in this report. Its composition is well shown by the analysis of D. 154 in table 1.'

This dull greasy-lustred coal is represented by three analyses in the present series, two from Korea and one from Bokaro, which are placed together in the following table : –

TABLE 6.—*Analyses of dull greasy-lustred coals or durain.*

Locality.	Korea.		Bokaro.
Number of specimen	D.151	K.2	F.175
	26·639	27 432	23·966
	Per cent.	Per cent.	Per cent.
Moisture	4·10	3·80	0·98
Volatile matter	19·10	22·28	22·05
Fixed carbon	43·52	38·96	37·60
Ash	33·28	34·96	39·37
TOTAL .	100·00	100·00	100·00
Specific gravity	1·64	1·61	1·65
Deviation from standard specific gravity (Korea 1·28 ; Bokaro 1·26) . .	+3	2	0
Caking properties	Does not cake		Cakes strongly.

There appears to be sufficient resemblance between the physical character and proximate chemical composition of these three specimens to permit one to accept them as representing a definite type. The differences in response to caking tests may be due to the different moisture contents of the Korea and Bokaro coals or to the conditions under which the tests were carried out, and not to any important difference between the specimens from Korea and Bokaro. It may be pointed out here that all the Korea coals are high in moisture and non-caking, or nearly so, as is shown in the table of analyses on p. 318.[1]

As one of these two types, namely the bright coal, must, when pure, be practically devoid of ash contents, it follows that the dull

[1] Further, the two coals from Skye discussed in the following paper (p. 359), which show still higher moisture contents, are also non-caking. See also page 349, and foot-note to page 327.

coal must contain the ash—in intimate association with the organic matter as already shown.[1]

With this dull greasy-lustred coal (omitting the enclosed macroscopically visible fragments of carbonised vegetable matter and veinlets of bright coal) and bright coal itself, we have apparently two roughly homogeneous types of coal. There is also one homogeneous type of carbonaceous shale namely that termed by me m.c. shale (micaceous carbonaceous shale) as represented by the analyses of F. 64 and F. 170 in table 2. It seems to me that the analysis of the data given on p. 33.; shows that with very few exceptions the Bokaro coals and carbonaceous shales may be regarded as compounded of these three types—bright coal (vitrain), dull coal (durain) and m.c. shale—sometimes in interlamination and sometimes in more irregular and intimate association. 'Mother-of coal' or 'mineral charcoal' (fusain) may occur in any of the types in thin films. The Korea specimens collected contain only the two first types mentioned, shaly coals and carbonaceous shales being absent. In addition macroscopically visible inorganic matter may be present, *e.g.*, lithomarge concretions in Korea coal and red hematite concretions in some Bokaro specimens.

These views concerning the composition of the coals of Korea and Bokaro based solely on a study of their proximate analyses, density, and macroscopic characters, are in accord with and receive support from the work of other observers, who, studying coals of other localities, have subjected their material to microscopic and chemical examination.

Thus A. Duparque[2], applying the metallographic microscope to the study of polished and etched surfaces of coals from the north of France, arrives at the following conclusions[3]:—

> 'Les observations exposées précédemment permettent de conclure, qu'abstraction faite de la substance minérale qu'elle contient, la houille est formée de deux éléments microscopiques.'

[1] But although this dull coal is to the unaided eye homogeneous it cannot be regarded as a simple compound of bright coal with inorganic matter. Microscopic examination would doubtless reveal the presence of plant entities such as spores not visible to the naked eye. The associated inorganic matter may in part be the original mineral matter of the plant contained in these entities, but it is at least in part doubtless of extraneous origin and, as indicated on p. 347. in colloidal association with the bright coal substance. See also Deparque's diagram page 342.

[2] 'Les quatre constituants de la Houille du Nord de la France', *Soc. Géol. du Nord, Annales*, L. pp. 56-79, (1926).

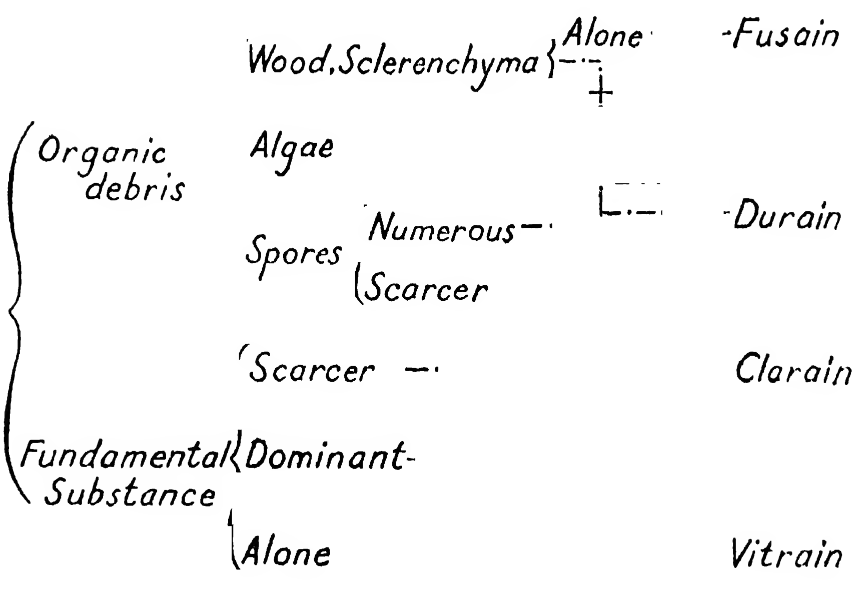
[3] *L. c.*, p. 70.

1. *Des débris végétaux* de nature différente qui se sont déposés dans un premier temps.

2. *Une substance fondamentale* de nature colloïdale qui est venue cimenter ces débris en passant successivement par les états liquide, colloïdal, puis solide, et qui dérive vraisemblablement de la dégradation ultime d'autres débris végétaux.

C'est la nature des premiers, l'absence de l'un ou de l'autre, ou leur combinaison, qui déterminent les quatre constituants macroscopiques de Mme Stopes'.

Then follow definitions of fusain, durain, clarain and vitrain and the following diagram (translated) illustrating the composition of each of these constituents :—



Vitrain, it will be seen, is identical with the 'fundamental substance.'

Professor Wheeler[1] in a paper on the 'Chemistry of Coal' read before the British Association arrives at conclusions that are practically identical with those of M. Duparque, although expressed

[1] *Journ. Soc. Chem. Ind.*, Vol. 46, pp. 848-853, (1927).

in different terms. Considering both coal and peat he states that two main types of material may be recognised :

(*a*) ulmins

(*b*) plant materials resistant to decay and to chemical treatment.

By chemical methods it is apparently easy to effect a ready separation of the coal-ulmins from the resistant plant-debris, and thus effect a rational analysis of the several components of a banded bituminous coal. The results of such an analysis of the four component bands of Hamstead coal are given as follows[1] :—

..	Ulmin compounds.	Organised plant entities.	Hydro-carbons and resins.	General character of plant entities.
	Per cent.	Per cent.	Per cent.	
Vitrain . . .	96	Nil	4	..
Clarain . . .	92	5	3	Cuticles and spore exines.
Durain . . .	83	15	2	Cuticles, spore exines and woody tissues.
Fusain . . .	20	80	Nil	Woody tissues.

Omitting fusain as an exceptional type it is seen that vitrain and durain are the normal end types and that clarain is equivalent to a mixture of vitrain and durain—in this case roughly 9 parts of vitrain to 4 of durain—durain itself being only vitrain with admixed resistant plant debris and finely divided mineral matter.

M. Duparque's[2] diagram confirms this view of the intermediate position of clarain. These results, therefore, of Messrs. Duparque and Wheeler support the view advanced earlier in this paper for Bokaro coals that omitting the unimportant fusain of 'mineral charcoal' we have to deal, in Bokaro banded bituminous coals, only with two fundamental constituents of organic origin, namely the colloidal 'pure coal' and the vegetable detritus, which in

[1] *L. c.*, p. 850.

[2] See also Duparque, *l.c.*, Planch IV, fig. 14.

practice yield the end forms bright coal (vitrain) and greasy-lustred dull coal (durain).

In so far as the mineral matter in coal represents the ash contents of the original plants it is doubtless at least in part present in the vegetable detritus still recognisable in the coal, and to this extent the ash contents of a coal may be roughly proportional to the amount of vegetable detritus present, although it must be remembered that the formation of vitrain has involved the destruction of vegetable tissues with release of associated inorganic matter. It is doubtless in part such mineral matter that is now in intimate association with organic matter as detected in the present research. In addition, there may be 'ash' or mineral matter of extraneous origin in either the colloidal condition or in mechanical admixture. These considerations lead us to the conclusion that our banded coals are composed of four constituents, which are :

(*a*) My 'bright coal', 'of the nature of a colloidal substance' —1914.

Dr. Marie Stopes' 'vitrain'—1919.

M. Duparque's 'Substance fondamentale de nature colloïdale' —1926.[1]

Prof. Wheeler's 'ulmin compounds' or 'ulmins' (with hydrocarbons and resins)—1927.[2]

(*b*) Vegetable detritus or organised plant entities (of which fusain may be regarded as the end form).

(*c*) Mineral matter in chemical or physical association (*e g.* colloidal).

(*d*) Mineral matter in mechanical admixture.

In practice these four constituents give three main types of roughly homogeneous carbonaceous substances, namely :-

1. Bright coal (vitrain) composed of *a*
2. Dull coal (durain) composed of $a + b + c$
3. M. c. shale composed of $d + (a$ or $b)$.

VII.—COMMERCIAL CLASSIFICATION.

This investigation seems to throw light upon the general nomenclature of coal. It also indicates suitable lines for the classifica-

[1] For an account of the 'gelée fondamentale' of Bertrand (1898) and other French geologists, reference may be made to Stopes and Wheeler, *l.c.*, p. 31.

[2] The term 'ulmin' was proposed as long ago as 1807 by T. Thomson, and has been adopted by Stopes and Wheeler in preference to 'humic substances', *l.c.*, p. 32.

tion of Bokaro coals for commercial purposes. It is unnecessary to discuss this in detail. Reference to the tabular statement in table 2 and to the diagram forming Plate 2 indicates that the following is a suitable classification of Bokaro coals for commercial purposes:—

TABLE 7.—*Commercial classification of Bokaro coals.*

Ash content.	Descriptive names.	Commercial classification.
Per cent.		
0—5 .	Bright coals	First and second-class coals dividing point 15 per cent. ash.
5—22 .	Silky coals, usually with bright bands	
22—33 .	Banded silky and shaly coals. Also granular coals.	Third-class coals.
33—50 .	Dull (silky to greasy-lustred) coals: banded shaly coals.	Fourth-class coals.
50—65 .	Coaly shales and carbonaceous shales	Coaly and carbonaceous shales
65—88 .	M.c. shales (micaceous carbonaceous shales.)	

The dividing point of 15 per cent. of ash between first and second-class coals does not arise from the investigation in this paper, but is based on custom and what is feasible with Bokaro coal. This classification is also suitable for the Korea coals as indicated in column 15 of table 1.

VIII.—COALS AS COLLOID SYSTEMS.

In the preceding sections of this paper the deductions drawn are based upon the actual experimental and observational data accumulated. Incidentally, however, reference is made (page 334) to a former suggestion of mine (1914) that the bright coal (*i.e.*, vitrain) of Korea is a colloidal substance, and this idea is now applied also to the vitrain of Bokaro. Reasons are advanced in support of this suggestion, but they are not sufficient to prove its correctness. Since this paper was sent to the press I have given further consideration to this point and it now appears to me that the statistical data contained in this paper themselves provide strong evidence of the colloidal nature not only of vitrain, but of the vitrain-

durain series. It would cause inconvenience now to attempt to modify the text throughout in conformity with this view, but I propose in this additional section briefly to indicate the manner in which the data given in the body of the paper can be explained in the light of colloidal systems, and in the following additional section (IX) to indicate the light that may be thrown upon practical questions connected with coal if one accepts the view that with some coals at least we are dealing with colloid disperse systems. This separate treatment is all the more appropriate because the data collected in this paper were obtained without any reference to the principles of colloid chemistry.

In the previous sections of this paper it has been shown that the Bokaro coals are made up of four constituents :—

Organic—

(*a*) Vitrain,

(*b*) Vegetable detritus,

Inorganic—

(*c*) Mineral matter in chemical or physical association with organic matter.

(*d*) Mineral matter in mechanical admixture with organic matter.

The intimate manner in which these constituents appear to be associated in coal renders it possible to regard these various associations as disperse systems. Disperse systems are in their simplest form two-phase systems of which one phase is known as the continuous phase (or dispersion medium) and the other as the disperse phase. Each of these phases may be either gaseous, liquid or solid. According to the size of the particles of the disperse phase the system is described as (1) a molecular dispersion (true solution), (2) a colloidal dispersion (emulsoid or suspensoid), (3) a coarse dispersion (emulsion or suspension), the range of size of colloid particles being roughly 0·0000001 cm. to 0·00001 cm. in diameter. Of these the molecular dispersion is an apparently homogeneous system, whilst the other two are heterogeneous systems, the particles of the colloid being ultramicroscopically visible, and those of the coarse dispersion visible under the microscope, or even macroscopically. In emulsoids and emulsions the disperse phase is liquid and in suspensoids and suspensions it is solid.

Of the four constituents of our Bokaro coals as listed above, we can treat (*b*), (*c*), and (*d*) as acting as disperse phases and (*a*) as a dispersion medium.

The aspect of coal that has been specially considered in this paper is the relationship of specific gravity to ash contents, or, in other words, of density to degree of concentration of the disperse phase. In the case of a coarse suspension, which is one form of mechanical mixture, the specific gravity of the system can be calculated from that of the two phases on the assumption of no change of total volume. But, in colloid solutions, owing to the fact that the disperse particles are so small that the ratio of surface to volume is large, so that surface energy comes into play, the specific gravity of the system cannot be so calculated. In fact with both colloid and molecular dispersoids, the density of the disperse system is different, usually higher, than for a mechanical mixture of the two phases, indicating that the association of these two phases has been accompanied by change of volume, usually contraction. In the case of molecular solutions, the density-concentration diagram is a curve concave towards the density co-ordinate. In the case of colloid solutions there is a difference between the type of diagram for emulsoids and suspensoids. Emulsoids give a curve concave towards the density co-ordinate, as with molecular solutions; but with suspensoids the density shows a linear increase with increase of concentration of the disperse phase, so that the curve expressing this relationship is a straight line.[1]

With the preceding introduction we can now mention that briefly speaking the data already given in preceding sections of this paper provide evidence for the following interpretation :—

(1) The coals of the vitrain-durain series of Bokaro and Korea form a series of colloid solutions (suspensoids) in which the vitrain is the dispersion medium and the ash content forms the disperse phase.[2]

[1] See Wolfgang Ostwald, 'A Handbook of Colloid Chemistry', Second English Edition, translated from the German by M. H. Fisher, p. 124, (1919). Later works on colloid chemistry give but little attention to density and concentration diagrams and it is possible that further research may not support Ostwald's criteria *in toto*. Thus some emulsoids and gels may yield convex instead of concave ones. Further, Ostwald's deduction that the density-concentration relationship for suspensoid systems is linear as based on data relative to systems of low degrees of concentration (*e.g.*, 4·4 per cent.). The present investigation relates to a type of system containing up to 40 to 50 per cent. of the disperse phase.

[2] The fragments of vegetable debris form an additional constituent, and as they are at least microscopically visible, they cannot be regarded as forming a part of a colloid system; instead they form a coarse dispersion (suspension) with the same dispersion medium as the colloid particles.

(2) The vitrain itself is a colloid system of the emulsoid or gel type in which it is uncertain whether the moisture or the complex of carbon compounds (or moisture-free vitrain) acts as the dispersion medium.

(3) The carbonaceous shales are mechanical mixtures of inorganic and organic matter.

(4) The shaly coals and coaly shales are the products of interlamination of vitrain and carbonaceous shale.

The deduction that the vitrain-durain series is a series of colloid solutions of the suspensoid type is based on the fact that the relationship between the density and ash contents of coals of this series is a linear one as demonstrated in a previous section. In the work by Wolfgang Ostwald to which reference has already been made it is pointed out (*l.c.* pp. 134—135) that in suspensoid systems the saturation concentration is usually very low, *e.g.*, 0·1 to 0·2 per cent. for colloid gold. Silver sols containing more than 30 per cent. of silver are mentioned, but it is suggested that this colloid concentration is due either to an admixture of impurities or that one is dealing with a coarse suspension. However, it is theoretically possible, if we assume that the disperse phase in a suspensoid is composed of rigid spherical particles, for the volume of the disperse phase to reach a maximum of about 74 per cent. of the total volume of the disperse system: whereas in both emulsoid and emulsion systems the disperse phase, because the particles thereof can be distorted, can occupy almost the whole of this space, as, *e.g.*, an emulsion of petroleum in soap solution in which as much as 99 per cent. of the former may form the disperse phase (*l.c.*, p. 138).

In our greasy-lustred shale-coal or durain we appear to have a suspensoid system containing from 33 to 39 per cent. of the disperse phase. As, in view of the preceding paragraph, this is a high degree of concentration, it is comforting to be able to point to refined Trinidad asphalt as a colloid system that has been shown to contain 35 per cent. of clay in the colloidal condition dispersed through a medium of bitumen.[1]

[1] Clifford Richardson, 3rd Report on Colloid Chemistry, pp. 98—102, (1920).

The density of the refined asphalt is given as 1·400. As this must be a suspensoid system the density-concentration relationship should be linear. As the disperse phase is probably the same in both the Trinidad asphalt and the Bokaro coals it seems likely that my rule for deducing the specific gravity of ash-free coal should be applicable to the Trinidad asphalt. This would give 1·400—0·354=1·046, or say 1·05 as the density of ash-free Trinidad bitumen.

Let us now consider the vitrain. It has already been pointed out in the footnote to page 327 that the specific gravity of certain coals increases with the moisture contents. If we confine our attention to analyses of vitrain only, we find that the available analyses, ten in number, of vitrain from the Bokaro, South Karanpura, Kurasia (Korea), Talcher and Pench Valley coalfields, and of two specimens from Skye, show the relationship between moisture and specific gravity, when the latter is reduced to an ash-free basis by application of my linear rule, that is expressed by the following figures :—

TABLE 8.—*Moisture and specific gravity of Indian vitrains.*

Locality.	Moisture.	Specific gravity of ash-free vitrain.	
	Per cent.		
Bokaro	1·21	1·252	Caking.
Do.	1·99	1·260	
Barkui (Pench Valley)	2·20	1·276	
Bokaro	2·24	1·264	
Argada (South Karanpura) . . .	6·27	1·289	
Korea	9·80	1·295	Non-caking.
Skye	11·41	1·303	
Do.	11·72	1·318	
Korea	13·02	1·303	
Talcher	15·08	1·323	

When the analyses are arranged in order of moisture contents, as in the foregoing table the regularity of the figures of specific gravity is seen to be spoilt by two analyses, namely the 3rd and the 8th, which show specific gravities somewhat too high for their position in the series. Neglecting these, the remaining eight analyses, when plotted as a density-moisture diagram, yield a well-marked curve.[1] This proves that we are not dealing with a suspensoid

[1] This is not given now, because specimens of vitrain from various additional Indian localities are being obtained in order to provide additional data. It appears to me, however, to be very remarkable that specimens collected from six different coalfields, two different countries, and two different geological periods (Carboniferous and Tertiary), should yield such a result.

system. That we are not dealing with a series of coarse suspensions or mechanical mixtures is proved by the fact that higher moisture or water is accompanied by higher density, instead of by a lower one, as would be the case for a mechanical mixture. This leaves us the choice of a molecular solution and a colloid system (an emulsoid or a gel). The fact that the moisture forms only from 1 to 13 per cent. by weight of the total seems to preclude us from regarding these vitrain specimens as molecular solutions, so that we seem compelled to accept vitrain as a colloid system. Whether in this system the moisture acts as the dispersion medium and the complex of carbon compounds (let us call this complex *moisture-free vitrain*) as the disperse phase or *vice versa*, we have no evidence, nor do we know whether the system should be regarded as an emulsoid or a gel, though the latter seems more likely.

Summarising it appears then that vitrain may be regarded as a colloid system, of emulsoid or gel type, of moisture and moisture-free vitrain[1]; and durain as a colloid system in which the vitrain acts as a dispersion medium containing two disperse phases, namely ash (suspensoid) and vegetable detritus (coarse suspension).

IX. PRACTICAL APPLICATIONS.

The relationship described in this paper between the specific gravity and ash contents of coal and the specific gravities and moisture contents of specimens of vitrain has been explained in a previous section on the basis of the properties of disperse systems, both mechanical and colloidal. The relationship is pointed out and the conclusions concerning the colloidal nature of some coals that follow therefrom enable one to offer definite suggestions on various practical problems connected with coal. Some of these suggestions amount really only to suggestions for further research by those who have the opportunity for such work. But it will probably be useful if I enumerate here such points as have occurred to me.

Suggestions can be offered under the following headings :—

(1) Prospecting for coal.

(2) Coal washing and flotation.

[1] This is the simplest treatment for vitrain. The 'volatile matter' and 'fixed carbon' also vary progressively with the specific gravity of vitrain and ultimately a less simple treatment may be necessitated by the data.

(3) Coking.
(4) Manufacture of liquid fuel from coal.

Prospecting for coal.

The linear relationship between specific gravity and ash contents that applies to the vitrain-durain series of coals enables any prospector who knows the fundamental specific gravity of ash-free coal of that series to determine in the jungle the ash contents of a lump of coal by the very simple expedient of taking the specific gravity with a Walker's balance. As he can in this way make a rapid ash analysis of as many varieties of coal as he likes, it is easy for him to form in the jungle a rough estimate of the quality of coal seams encountered and to determine then and there whether the expenditure and time necessary for careful sampling is justifiable (see page 326). Although this method is strictly applicable only to coals belonging to the vitrain durain series it can also be used for mechanical mixtures represented by shaly coals without serious error (see page 334).

Coal washing and flotation.

Any attempt to beneficiate or improve the quality of coal by methods of washing and flotation depends obviously upon the state of association between the organic and inorganic constituents of the coal. It will be accepted as obvious that neither of these methods can have any hope of success when applied to colloidal systems, that is to say, to the vitrain-durain series, except in so far as a particular coal has a portion of its vitrain segregated into definite bands. In the case of the mechanical mixtures represented by interbanded vitrain and carbonaceous shale on the other hand, the difference between the specific gravity and other properties of the vitrain and of the carbonaceous shale is so high that, given a sufficiently high proportion of vitrain, the beneficiation of the coal by methods of flotation or washing, may conceivably be an economically feasible proposition.

Coking.

The factors in the composition and constitution of a specimen of coal that may confer upon it the property of yielding coke when heated under suitable conditions do not appear to be fully understood. This investigation seems to throw light upon one factor that may be of material importance. It has been thought that the presence of vitrain is helpful to the coking properties of a coal and the presence of durain is

inimical thereto. This investigation shows, however, that the problem is not so simple. A reference to the figures given on page 349 will show that if one can judge coking properties of a coal from the ordinary laboratory determinations of caking properties. then with vitrain the ability to coke is in part a function of moisture, for those coals with the lower moisture show caking properties and those with higher moisture show non-caking properties.[1] The analyses of dull greasy-lustred coal (durain) given on page 340 from Korea and Bokaro tell the same story. The Bokaro durain with 39 per cent. of ash and 1 per cent. of moisture cakes strongly. The two specimens of durain from Korea with 33 to 35 per cent. of ash and about 4 per cent. of moisture do not cake. On comparing the data for vitrain with the data for durain we see that even 39 per cent. of ash contents does not harm the ability of the coal to cake; but that with both vitrain and durain high moisture is accompanied by absence of caking properties.[2] It does not follow that these observations will prove to be applicable to all coals, for it will be noted that all the coals now under consideration with the exception of the two specimens from Skye are of Palaeozoic age.

On the practical side one might think that, on the basis of these observations, it should be easy to convert a non-coking coal into a coking coal merely by the operation of reducing the moisture contents. The problem is probably not as simple as this, for in the ordinary process of determining the 'moisture' contents of coal the moisture is driven off without converting the coal into a caking coal. This moisture, moreover, is not loosely held hygroscopic moisture, but is obviously much more intimately associated, if my interpretation is correct that it forms a separate phase in the vitrain colloid system. The results obtained from practical tests on a large scale do not, however, always agree with those obtained in the laboratory, so that large-scale experiments upon the removal of moisture from a non-coking coal otherwise similar in analysis to low-moisture coking coals would seem to be worth while. The ordinary processes of making coke result in the rapid application

[1] Moisture is, of course, not the only factor that counts. The same data show also a regular change of volatile matter and fixed carbon with moisture and specific gravity. Further data are being collected and it is hoped to discuss vitrain analyses in a later paper.

[2] Since this paper was sent to the press, Mr. Balaram Sen of the Tata Iron and Steel Co., Ltd., has described before the Indian Science Congress at the Calcutta meeting, January 1928, the results of a large series of practical tests directed to ascertain the factors that confer coking properties upon coal. He finds that high ash does not prevent a coal from coking, but that high moisture does, his results proving thus to be in accord with mine.

of heat to the material being under treatment with the result, no doubt, that the carbon compounds are affected by the heat before any considerable reduction in the moisture contents has been effected. It may, therefore, be offered as a suggestion worth practical test that it may conceivably be possible to convert a suitable non-coking coal into a coking coal by holding it for a considerable time at a temperature sufficient to remove the 'moisture' contents before raising the temperature of the coke-oven to heights that will effect a breaking up or distillation of the carbon compounds.

Manufacture from coal of liquid fuel.

If one accepts the view that certain coals may be regarded as colloid systems, it seems possible to outline theoretically the broad steps necessary to convert such coal into liquid fuel. The apparently solid condition of the coal may be regarded as due to the high viscosity of the vitrain. The first step, therefore, would be one that reduces this viscosity to such an extent that the carbon compounds possess the properties of a mobile fluid. The modern method of hydrogenisation, which is directed towards lowering in their respective series the hydrocarbon compounds contained in coal, is obviously a method of effecting this result. Should the coal thus treated be an impure one with a large amount of mineral matter in colloid solution then the process of treatment would presumably result in the production of a liquid fuel still containing such particles in the colloidal condition. Two methods appear to suggest themselves of purifying the liquid fuel from these colloid particles. One is obviously the method of distillation, which results in the ash contents being left behind. The other would be the addition to the fuel of some electrolyte—should this be practically feasible—for the purpose of causing the coagulation and precipitation of the colloid mineral particles.

X.—SUMMARY.

1. In studying a mineral deposit it is desirable not only to take average samples, but also to choose carefully hand-specimens representing the various mineral types present and then to subject these specimens to the test of assay or chemical analysis conducted on pieces of which the specific gravity has been determined.

2. Such work on specimens derived from the coal seams of Korea State, C. P., in 1913 led to the discovery of a definite empirical

relationship between the ash contents and density of a coal. Taking the specific gravity or density of pure ash-free Korea coal (bright coal) as 1·29 (k), the ash contents (a) of other Korea coals of density g was found to be very closely, with one exception, governed by the empirical straight-line rule

$$a = 100\ (g - k).$$

3. Such a rule, if of general application, would obviously be of the first importance to the prospector, as by determining the specific gravity of representative specimens of coal with a Walker's balance in the field he could determine roughly the ash contents of each type and therefore of any seam, and thus decide in the field whether a seam was worth proper sampling for analysis.

4. In the course of an investigation of the Bokaro coalfield during 1916 and 1917 the rule discovered in Korea was tested further by the selection and analysis of a much larger series of picked specimens, carbonaceous shales as well as coals being taken into the investigation.

5. The results given in table 2 show that in most cases this empirical rule applies to coals containing up to 50 per cent. of ash, the fundamental specific gravity constant (k) being in this case 1·26 instead of 1·28, the constant finally adopted for Korea. All the specimens from both fields come from the Barakar series.

6. The results are plotted in Plate 26, from which it is seen that in carbonaceous shales (that is those carbonaceous substances with over 50 per cent. of ash) the empirical rule no longer applies, the specific gravity of the carbonaceous shale being increasingly in excess of that indicated by the rule (which corresponds to a straight line as indicated in the diagram).

7. Discussing for the present only coals (carbonaceous substances with not greater than 50 per cent. of ash), we find that in certain cases the coals have a specific gravity seriously above or below those indicated by the empirical rule. These deviations are indicated by plus and minus signs (tables 1, 2, and 4).

8. The plus and minus coals are represented in the diagram in Plate 26 by spots respectively above and below the curve.

9. The plus coals are found in the one case studied to owe their high density to ash abnormally rich in oxide of iron, and therefore presumably of abnormally high density (see page 325).

10. The zero or normal coals, which are those agreeing with the empirical curve (a straight line), have, nevertheless, a higher

density than figures obtained by calculation of the specific gravity of mechanical mixtures of pure coal and pure shale. This fact is taken as indicating some form of chemical or physical combination with decrease of volume between the organic and inorganic matter in coals with ash contents up to 45 per cent. of ash (see p. 333 and Plate 27).

11. The minus coals are ones with a density less than that required by the empirical rule. In one case the low figure (—13) was not confirmed on repetition of the work. But the figure of —7 for one Korea coal has been confirmed, and this coal, with two Bokaro coals showing deviations of -2 and -5, may be examples of coals in which this intimate association between organic and inorganic matter does not exist, so that the specific gravity conforms to that indicated by calculation for mechanical admixture. (See table 4).

12. With ash in excess of 50 per cent. (carbonaceous shales) the empirical straight-line rule is no longer followed, and instead it is found that the density-ash curve is closely that for mechanical mixtures of coal of density 1·26 and shale of density 3·00 (See table 4).

13. This curve crosses the straight line representing our empirical rule at 45 per cent. of ash. With ash below 45 per cent. only minus coals follow the calculated curve, most coals then following the straight-line law (zero or normal coals); consequently the space between the two curves indicates condensation of volume due presumably to some form of chemical or physical association of the coal with its ash contents.

14. Our carbonaceous substances are thus roughly divisible into (1) coals with not greater than 50 per cent. of ash and in which the ash, if not greater than 45 per cent., is at least partly in chemical or physical association with the carbonaceous contents, and (2) carbonaceous shales with greater th n 50 per cent. of ash in which the organic and inorganic matter behave as if in mechanical admixture.

15. The macroscopically homogeneous substances making up the majority of the Bokaro and Korea coals are three in number (see p. 341), namely the fundamental colloidal substance or bright coal (vitrain), greasy-lustred dull coal (durain), and m.c. shale (micaceous carbonaceous shale). 'Mother-of-coal' (fusain) is seen sometimes in films. The dull greasy-lustred coal carries 33 to 39 per cent. of ash and has a density of 1·61 to 1·65. It may be expected to carry

a portion of its mineral matter in a state of chemical or physical association with the organic matter.

16. An analysis of the data, taking account of both the actual macroscopically visible characteristics of the coals and of their specific gravity deviations, shows that our Bokaro specimens can be arranged into two series :—

	Ash contents.	Specific gravity.	Deviations.
	Per cent.		
I. Vitrain-durain series (Bright, silky, and dull coals).	2·31 to 39·11	1·28 - 1·65	
II. Vitrain-carbonaceous shale series. (Shaly coals, coaly and carbonaceous shales).	27·61 to 89·11	1·49 2·58	– 5 to + 45

17. The Korea specimens all belong to the vitrain-durain series with ash contents ranging from 0·51 to 34·96 and specific gravity from 1·30 to 1·61.

18. A consideration of the data given in table 2 and Plate 26 leads one to suggest that the most useful commercial classification of the Bokaro coals would be as follows :—

Ash contents.	Descriptive names.	Commercial classification.
Per cent.		
0 – 5 .	*Bright coals*	First and second-class coals : dividing point 15 per cent. of ash.
5 – 22 .	*Silky coals* usually with bright bands .	
22 – 33 .	*Banded* silky and shaly *coals*. Also granular coal.	Third-class coals.
33 – 50 .	*Dull* (silky to greasy-lustred) *coals* : shaly coals.	Fourth-class coals.
50 – 65 .	*Coaly shales* and carbonaceous shales .	Coaly and carbonaceous shales.
65 – 88 .	*M.c. shales* (micaceous carbonaceous shales)	

This classification also applies to the Korea coals.

19. If one treats these coals as disperse systems, consideration of the density-ash relationships discussed in sections III and IV shows that the vitrain-durain series can be treated as a series of suspensoid colloid systems in which the vitrain acts as the dispersion

medium, and the ash contents as the disperse phase (suspensoid) with the vegetable detritus contained in the durain as a second disperse phase (coarse suspension).

20. Similarly, consideration of the fact that in a series of analyses of vitrain from various localities the specific gravity increases with the moisture enables one to deduce that vitrain itself is an colloid system (emulsoid or gel) in which the moisture-free vitrain and the moisture may be regarded as separate phases.

21. On the basis of the data collected in this paper and the interpretation of coals as colloids, it is possible to offer suggestions on certain practical aspects :—

1. Prospecting.
2. Coal-washing and flotation.
3. Coking.
4. Production of liquid fuel from coal.

Reference to prospecting is made in paragraph 3 above. We need refer here only to coking, by mentioning that the vitrains and durains lower in moisture are caking and those higher in moisture are non-caking.

LIST OF PLATES.

NOTE ON A CONTACT OF BASALT WITH A COAL-SEAM IN THE ISLE OF SKYE, SCOTLAND: COMPARISON WITH INDIAN EXAMPLES. BY L. LEIGH FERMOR, O.B.E., D.SC., A.R.S.M., F.G.S., *Officiating Director, Geological Survey of India.*

IN the summer of 1914 I enjoyed the privilege and good fortune of spending several weeks in Skye in the company of Dr. A. Harker. Amongst many interesting sections visited one was of special interest.

In the cliff a little south of Dúnan Earr an Sgúirr, between Loch Brittle and Loch Eynort, the little ravine of Allt Geodh' a' Ghamhna shows a section of some 30 feet of conglomerates and tuffs with coal seams, intercalated in the succession of Tertiary basaltic lava flows of Skye, and analogous in position to the Intertrappean beds of the Deccan Trap lavas of India. Details of this section are given on page 26 of Harker's *Tertiary Igneous Rocks of Skye*, and may be abstracted as follows:—

Basaltic lavas, with sills, above.

Coal-seam	0—3 in.
Tuff	1 ft.
Coal-seam	0—3 in.
Conglomerate	6—7 ft.
Tuff with impure coal-seam (6 to 8 inches) in lower part	5—7 ft.
Conglomerate	5—6 ft.
Tuff	2½—3 ft.
Conglomerate	about 9 ft.

Basaltic lavas, with sills, below.

The conglomerates all possess a tuff matrix.

My interest was aroused by the fact that although the lava was resting directly on the uppermost seam of coal there was no visible difference between this coal and that of the lower seams, except in a very thin surface layer, not more than 0·5 mm. thick, of the uppermost seam.

Owing to denudation the details of the section have, of course, changed somewhat since Dr. Harker's previous visit some years before. Confining myself to the upper parts of the section I found

that at the point examined the lower of the two upper seams noted above was about ½ inch thick and rested directly on the conglomerate, following the curves of the pebbles. It was overlain by 3 to 4 inches of sandy tuff containing carbonised plant remains followed by two more thin coal seams, each ⅛ to ½ inch thick and separated by 1 to 2 inches of tuff tending to be shaly: these two seams and the tuff together correspond to the uppermost coal-seam of Dr. Harker's section. The upper of these two coal seams was overlain by vesicular and amygdaloidal earthy basalt resting on it in immediate contact. I collected specimens of these two upper coal seams and these have been analysed in the laboratory of the Geological Survey of India by Mahadeo Ram, with the results shown in columns A and B below. It will be seen at once that the upper coal seam (28/826) is practically identical in composition with the coal seam (28/827) 2 inches below, from which it seems evident that the lava has produced no appreciable effect on the upper coal and therefore cannot have been very hot by the time it came in actual contact with the coal or the vegetable matter from which the coal has been formed.

— —	A Lower coal seam (28/827) Picked material.	B Uppermost coal seam (28/826) Picked material.	C Crust from 28/826.	D Residue per 100 grams of coal assuming ash constant in changing from B to C.	E Percentage loss.
Moisture	11·41	11·72	16·71	7·03	40·02
Volatile matter	30·85	31·25	45·20	19·03	39·10
Fixed carbon	53·53	52·98	28·47	11·99	77·37
Ash	4·21	4·05	9·62	4·05	..
Coking properties	Does not cake	Does not cake	Does not cake	..	..
Colour of ash	Light brown	Brown	Light grey	..	..
Specific gravity	1·315	1·359	..	..	..

Each of these coals is a jointed pitchy-lustred coal of lignitic aspect with conchoidal fracture; but the actual surface of the upper seam (28/826) has a somewhat 'sintered' aspect, which is seen through a lens to be due to minute polygonal jointing at right angles to the surface of the coal: this layer is about 0·5 mm. thick. Some of this altered coal was scraped off and analysed, with the

result shown in column C of the table. It was impossible to be certain that the material so obtained was free from portions of the underlying unaltered coal; consequently this analysis must be taken as an expression of the change produced by the lava at its contact with the coal rather than as a full measure of the change. It shows apparently a marked increase in ash, volatile matter, and moisture, and a decrease in fixed carbon. But if we assume that the quantity of ash in the coal undergoing modification has remained a constant, then it is evident that 2·38 parts of coal have yielded 1 part of altered coal, with the percentage losses shown in column E, from which it is interesting to note that the percentage loss of fixed carbon has been nearly twice as great as that of volatile matter and moisture.

It is interesting to contrast this case with the contact metamorphic effects produced by basic dykes intruded into coal seams. In the case of the mica-apatite-peridotite dykes of the Giridih coalfield, India,[1] a 4-ft. dyke has produced a coked zone in the coal $3\frac{1}{2}$ ft. wide, with a resultant great increase in the proportion of fixed carbon to volatile matter. Similarly a 'white trap' dyke (originally basalt) 1 to 4 feet thick, intruded into a coal seam in the Barkui colliery, Pench Valley coalfield, India,[2] has altered the coal to a distance of 12 inches from the contact. As the Pench Valley coal is a non-coking coal according to [illegible]r. F[illegible],[3] the amount of coking effected at the contact was very small, but the altered coal showed a considerable increase in the fixed carbon relative to volatile matter.

It is thus seen that the effect of the lava of Skye on the ratio of fixed carbon to volatile matter is the reverse of that of the basic dykes on seams of completely-formed coal. No obvious explanation of this difference offers itself.

But it seems possible to explain why the Skye lava has made its presence felt only for a fraction of a millimetre, whilst the dykes referred to above have altered the coal to a distance of 1 to 4 feet from the contact. In the latter case the molten lava occupying the fissure must have been very hot, have come into immediate contact with dry or relatively dry material, and have cooled more slowly than a surface lava. On the other hand it is evident that

[1] T. H. Holland & W. Saise, *Rec. Geol. Surv. Ind.*, XXVIII, pp. 132–5, (1895).
[2] C. S. Fox, *Rec. G. S. I.*, XLIV, pp. 123–136, (1914).
[3] But see *Mem. G. S. I.*, XLI, p. 185.

the lava of Skye must have been relatively cool by the time it came in contact with the vegetable matter that is now coal. But the ordinary temperature of basaltic lava in the molten condition may be taken as approximately 1000°C.[1]: consequently it is of interest to enquire how the vegetable matter that is now coal escaped alteration except in its topmost film. The answer is seen in the physical character of the lava. It is now an earthy vesicular rock with the vesicles occupied by calcite and a chloritic substance. Vesicular structure at the base of a lava flow may be explained in two ways. The surface of a flow cooling in contact with the air assumes a vesicular character due to the expansion of dissolved or entangled gases under atmospheric pressure. During the flow of the lava portions of the vesicular surface may be rolled underneath the flow at the advancing front. This, however, could not happen in the case of a very fluid, rapidly flowing lava, so that the base of a basaltic lava flow should sometimes be non-vesicular, as, judging from the Indian Deccan Trap flows, seems often to be the case. If, however, the lava should flow into a shallow body of water, such as a freshwater pool or lagoon, it must to a large extent displace the water. Any water that becomes imprisoned below the flow must be vaporised and penetrate into the base of the lava and render it vesicular. This water must also act in another way: in the form of steam it must act as a cushion and prevent the hot lava from coming at once into contact with the bottom of the pool, so that a layer of vegetable matter lying there would be protected from the lava by vapour until the lava had become too cool to have much effect on this vegetable matter. There would also be a great abstraction of heat from the lava in the process of heating and vaporising the water, and this would cause a more rapid freezing of the base of the flow than if the lava were flowing over dry land.

The foregoing seems to explain in a reasonable manner why only the actual upper surface of the vegetable matter in our Skye case was affected by the lava. The constitution of the vegetable matter before the advent of the overlying lava is difficult to deduce, but if the change in the surface of the upper seam is really a form of coking it looks as if this vegetable matter must already have been somewhat compacted and on the way to coal before the lava was erupted.

[1] Harker: 'Natural History of Igneous Rocks', pp. 185—6.

Similar cases of actual contact of a lava flow with coaly matter have been described by Sir A. Geikie[1] from both Skye and Canna in the Western Isles of Scotland, and in only one case is it noted that the lava has had a contact effect on the vegetable matter. This is at Cul nam Marbh, Canna, where a coniferous tree stump, apparently growing *in situ*, has been charred (*l.c.*, p. 362); it is conceivable that this stump was projecting above the water in which the associated vegetable matter was deposited, so that it came in immediate contact with the hot lava.

[1] *Q. J. G. S.*, LII, pp. 341, 359, and 362, (1896).

THE BARAKAR-IRONSTONE BOUNDARY NEAR BEGUNIA, RANIGANJ COAL-FIELD. BY CYRIL S. FOX, D.SC., M.I.MIN. E., F.G.S., *Officiating Superintendent, Geological Survey of India* (With Plates 28 and 29.)

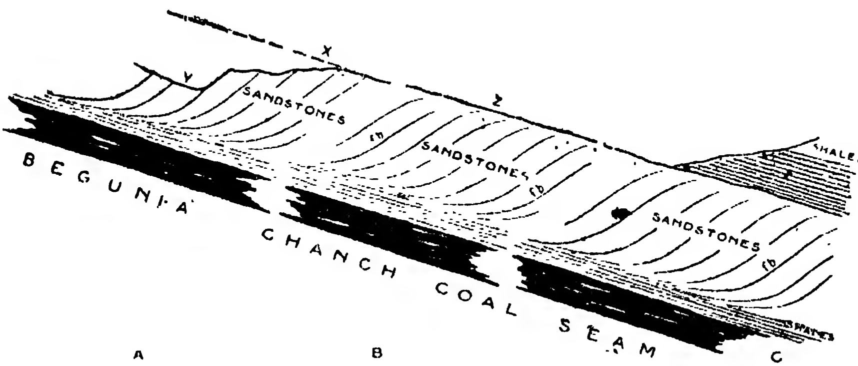
THE re-survey of the Raniganj coal-field now in progress has shown that the junction between the Barakars and the overlying Ironstone Shales is normally a conformable one. It is at a higher geological horizon than is suggested by its position, north of the Grand Trunk road at Begunia, on Blanford's map. This junction really follows a line in a W.S.W. direction from north of Kulti and south of Begunia to the Barakar river. It is a faulted boundary. The shales shown in the sketch of the Jain temple section by W. T. Blanford[1] are carbonaceous, but they do not contain ironstone, and for this reason should be included in the Barakars. Furthermore these shales are overlain by the pebbly sandstone, of a Barakar facies, which forms the ridge on which Begunia is situated. It has, however, been difficult to explain the apparent remarkable unconformity to which Blanford drew attention.

While working on about the same geological horizon, *i.e.*, above the Chanch seam, which is the westward continuation of the Begunia seam, in the Khudia *nala* near Chanch, I discovered an exposure showing the finest example of false- or current-bedded sandstone that I have seen. The real dips of this sandstone are to the south-east while the planes of current bedding dip northward. (Plate 2[illegible]). It immediately occurred to me that, as this sandstone was almost certainly the same as that on which the Jain temples at Begunia stand, the northerly dips, which are so evident in the sandstones between Begunia and Barakar, might really be the dip of planes due to current bedding. (Plate 28, fig. 2.) On careful examination, particularly of a small quarry, which was not open in Blanford's day, just north of the Grand Trunk road and east of the road to Barakar station, I found that the planes of apparent bedding do not continue to the surface of the sandstone. This they should do if the surface of the sandstone was a weathered and eroded unconformity. The low southerly dip is the true dip of

[1] *Mem. Geol. Surv. Ind.*, III Art. 1, (1865), p. 42.

these sandstones. It agrees with the dip slope of the sandstones at the Jain temple exposure, as well as with the southerly dip seen in the Chanch (Khudia) section. The northerly dips in the quarry are undoubtedly those of the planes of false-bedding. This will be seen from a scrutiny of Plate 28, fig. 2. In short there is no 'roll' of the beds, and certainly no unconformity. The exposures in that area convey a wrong impression to the mind if the meaning of the details in the quarry section is not grasped. Without the quarry section, which was not open in Blanford's time, it would be quite impossible to arrive at any other conclusion than that of Blanford. A true explanation of the observed facts is shown in the accompanying sketch section.

FIGURE 1.



A. EXPOSURES SOUTH OF BARAKAR.

It is wrong to assume an anticlinal at X. This would make the beds at Y above those in the Jain temple section.

B. SECTION IN QUARRY.

The false bedding planes, *fb*, although sharp, do not run out to the true dip slope at Z.

C. SECTION AT JAIN TEMPLES, BEGUNIA.

Here dip slopes have so far only been seen. The false bedding has not been recognised in the dirty pool below the temple.

LIST OF PLATES.

THE RANIGANJ-PANCHET BOUNDARY NEAR ASANSOL, RANIGANJ COAL-FIELD. BY CYRIL S. FOX, D.SC., M.I.MIN.E., F.G.S., *Officiating Superintendent, Geological Survey of India.* (With Plates 28 and 30.)

IN his survey of the Raniganj coalfield W. T. Blanford (*Mem. Geol. Surv. Ind.*, III, pp. 126–131) gives a short clear description of the Panchets and states (p. 127) that there is a slight unconformity between the Panchet and the underlying Raniganj stage. He does not, however, mention the fossil-wood horizon in which the fossil tree was found near Asansol. The re-survey of the Raniganj coalfield has now proceeded far enough for a definite opinion to be given with regard to the exact boundary between the Raniganj stage and the overlying Panchet beds.

Mr. Sethu Rama Rau, Assistant Superintendent, Geological Survey of India, working south of the Damuda river, has found a well-marked fossil-wood sandstone almost at the top of the Raniganj stage. Mr. A. K. Banerji, Assistant Superintendent, Geological Survey of India, working from the Damuda river north-eastwards by Patmohna and Hirapur to the Kumarpur railway cutting on the East Indian Railway two miles west of Asansol, has traced the same fossil-wood horizon to this place, and finds that this horizon must be included in the Raniganj stage and not in the Panchet stage. I have seen the chief sections on which Mr. Banerji bases his opinions and agree with him that there is a slight but local unconformity (Plate 28, fig. 1) between the undoubted Panchet beds and the underlying strata in which the fossil wood sandstone occurs. This fossil-wood sandstone is of considerable value as a stratigraphical horizon, as it can be followed across the whole of the western part of the Raniganj coalfield.

The fossil tree erected in the Indian Museum comes from the fossil-wood sandstone exposed in the Kumarpur railway cutting west of Asansol. This tree, according to Professor B. Sahni, belongs to 'the Cordaitales, one of the most important groups of Palaeozoic Gymnosperms.' Details of the discovery are given in the *Records, Geological Survey of India*, LVIII, pt. 1, 1925, pp. 75-79. In this account it was stated that the sandstone in which the silicified tree trunks were found belongs to the Panchet beds. The reasons

for this opinion are not stated. I found another silicified tree trunk in the same cutting in October 1925 (Plate 30, fig. 2). This was extracted and brought to Calcutta but has not yet been mounted. It was nearly 50 feet long as it lay when fully exposed. Professor Sahni, considered that the first tree belonged to the genus *Dadoxylon* and showed well-marked growth rings (Plate 30, fig. 1). He gave no name for the species. He, however, drew attention to the fact that it was very similar to two species—namely *D. indicum*, Holden, from Deogarh, and *D. bengalense*, Holden—from Brahmanbarari in the Jharia coalfield. Both these species were from the Barakar stage of the Damuda series (Lower Gondwanas). Seeing that the palaeontological evidence supports a Palaeozoic rather than a Mesozoic age I feel that an uppermost Raniganj age rather than a lowest Panchet age must be accepted for the fossil-wood sandstone and suggest that its official designation might be the Kumarpur (fossil-wood) sandstone.

This is the only fossil-wood (silicified) horizon known in the Lower Gondwanas, and should it be also found to occur in the eastern part of the Raniganj coal-field, will be of great use as a stratigraphical horizon.

LIST OF PLATES.

PLATE 28, FIG. 1.—Panchet-Raniganj unconformity in stream near Junut village, Raniganj coalfield.

PLATE 30.—FIG. 1.—Fossil tree from Kumarpur railway cutting showing rings of growth.

FIG. 2.—Fossil tree in Kumarpur railway cutting.

A PERMO-CARBONIFEROUS MARINE FAUNA FROM THE UMARIA COAL-FIELD. BY F. R. COWPER REED, M.A., SC. D., F.G.S. (With Plates 31 to 36.)

INTRODUCTORY REMARKS.

THE fossils described in this paper were collected from beds associated with those of undoubted Lower Gondwana age at Narsarha railway cutting, Umaria, Rewah State, Central India, in 1922, but the presence of marine fossils at this locality had been observed in the previous year. A brief note on their occurrence was published in the General Report of the Geological Survey for 1921 [1], but no precise determination of the specimens was given. In this report it was observed that the most abundant fossil was a species of *Productus* which Mr. Tipper considered to be new to India; and this shell forms practically the whole of the shell-band, 3 inches thick, which contains most of the fossils. Another brachiopod attributed to *Spiriferina* was also mentioned, and it was regarded as "close to and probably identical with *Sp. cristata* var. *octoplicata*." The shell-band is described as resting on quartz-grits which pass up conformably through it into sandstones of Lower Barakar age.

The description of these fossils, which were sent to me for identification in 1925, had been finished and the plates to illustrate them had been drawn when further material collected by Mr. E. R. Gee in 1926, was submitted to me, necessitating a revision of my previous work and throwing further light on the stratigraphical age of the beds. These new fossils were found in the same locality on both sides of the Narsarha railway cutting two miles west of Umaria railway station in four distinct bands, the lowest one D, (K 23·264) containing large numbers of small gasteropods in a gritty clay; the next one, C, (K 23·263) lying 2½ feet higher and containing chiefly brachiopods, in red and olive-green clays associated with the *Productus* shell-band and about 8-9 inches below the succeeding horizon, B, (K 23·262) which is a yellow brown sandy clay 1½ inches thick. The highest horizon, A, (K 23·261) is an 8-inch band in the soft fine yellow sandstone of the basal Barakar series, and contains many specimens of *Productus*, *Pleurotomaria*, etc.

[1] Fermor, *Rec. Geol. Surv. Ind.*, Vol. LIV, pt. 1, August 1922, pp. 14-16; *Nature*, Vol. CX, 1922, p. 556; Wadia, 'Geology of India', 2nd edit., 1926, London, p. 118.

The great interest and importance of marine fossils occurring in the Gondwanas of Central India were recognised in 1921, and the determination of their affinities as a guide to the stratigraphical horizon of the beds has therefore demanded particularly detailed study.

The material at first submitted to me in 1925 consisted of masses and slabs of the shell-band mainly composed of more or less imperfect specimens of *Productus* densely aggregated; there were also a few loose specimens weathered out free from the matrix. Some of the slabs were in a rotten crumbling condition, the matrix being of a soft friable argillaceous nature and falling to pieces on exposure, so that the extraction of more than fragments of fossils was difficult. But it was from material of this character that the first specimens of the small *Pleurotomaria*, *Rhombopora* and ostracods were picked out.

The harder masses of rock forming the shell-band do not consist of anything but agglomerated shells of *Productus*, mostly of one species, with here and there a crushed specimen of the small *Pleurotomaria*. On the softer pieces of rock other fossils also occur, and frequently they have their minute surface-ornamentation beautifully preserved. The specimens in this first collection, however, were in nearly every case fragmentary and very imperfect, so that it was difficult to arrive at any satisfactory conclusions. The new material collected subsequently by Mr. Gee is fortunately in a much better condition, and several new species not previously observed have been detected, while it has been possible to define the characters and ascertain the affinities of the others more precisely. A certain number of shells belonging to species of *Productus*, *Spirifer*, *Reticularia* and *Pleurotomaria* occur loose and almost free from matrix, and some are in a good state of preservation. As above noticed, they occur in several distinct bands of rock which contain slightly different assemblages of fossils, but most of them are common to all the horizons and no important difference in age can be established.

DISTRIBUTION OF THE SPECIES.

(*First Collection*).

K 21·424 . . . *Productus umariensis* sp. nov.
,, ,, var. *spinifera*.
,, *rewahensis* sp. nov.
,, ,, var. *coroides*.

	Spirifer narsarhensis sp. nov.
	,, ,, var. *pauciplicata.*
	Reticularia barakarensis sp. nov.
	Orthotichia ?? sp.
K 21·425 . . .	*Rhombopora* sp.
	Productus umariensis sp. nov.
	Spirifer narsarhensis sp. nov.
	Athyris aff. *protea* Abich.
	Pleurotomaria umariensis sp. nov.
	Cytherella ? sp.
	Palaeocypris sp.
	Jonesina ? sp.
K 21·426 . . .	*Productus umariensis* sp. nov.
K 22·972 . . .	*Pleurotomaria umariensis* sp. nov.
K 22·973 . . .	*Pleurotomaria umariensis* sp. nov.
	Dermal tubercles of fish.
(*Second Collection.*)	
Horizon A (K 23·261)	*Productus rewahensis* var. *coroides.*
	Spirifer narsarhensis.
Horizon B (K 23·262)	*Spirifer narsarhensis.*
	,, ,, var. *pauciplicata.*
	Reticularia barakarensis.
	,, ,, var. *subplicata.*
	Crinoid stem and joints.
	Dermal tubercles of fish.
Horizon C (K 23·263)	*Productus rewahensis.*
	,, *umariensis.*
Horizon D (K 23·264)	*Productus rewahensis.*
[=K 22·972, 933]	*Janeia* aff. *biarmica* (De Vern.)
	Pleurotomaria umariensis.
	Crinoid stems.
	Dermal tubercles of fish.

(K 23·265) (From east side of railway cutting.)
Productus umariensis.
Spirifer narsarhensis.

COMPLETE LIST OF FOSSILS.

Crinoidal stems and joints (K 23·262) (K 23·264).
Rhombopora sp. (K 21·425).
Productus umariensis sp. nov. (K 21·424), (K 21·425) (K 21·426).
,, ,, var. *spinifera* (K 21·424).
,, *rewahensis* sp. nov. (K 21·424) (K 23·263) (K 23·264).
,, ,, var. *coroides* (K 21·424) (K 23·261).
Spirifer narsarhensis sp. nov. (K 21·424) (K 21·425) (K 23·262).
,, ,, var. *pauciplicata* (K 21·424) (K 23·262).
Reticularia barakarensis sp. nov. (K 21·424) (K 21·425) (K 23·262).
,, ,, var. *subplicata* (K 23·262).
Athyris aff. *protea* Abich (K 21·425).
Orthotichia ? sp. (K 21·424).
Janeia aff. *biarmica* (De Vern.) (K 23·264).
Pleurotomaria umariensis sp. nov. (K 21·425) (K 22·972).
(K 22·973) (K 23·261).
Jonesina ? sp. (K 21·425).
Cytherella ? sp. (K 21·425).
Palaeocypris sp. (K 21·425).
Dermal tubercles of fish (K 22·973) (K 23·262) (K 23·264).

DESCRIPTION OF THE FOSSILS.

Crinoidal stem and joints.

Pl. 36, figs. 15, 15a.

There is one portion of the stem of a crinoid (K 23·262) of a regular cylindrical shape measuring 6·5 mm. in length and 4 mm. in diameter and consisting of six joints of rather unequal thickness. The periphery of each joint is gently convex and smooth; the articulating face has an outer marginal ring of about 32 short coarse radial ridges extending inwards for about one-fifth to one-fourth of the diameter; the rest of the articulating surface is smooth and

somewhat depressed, with a large central circular canal nearly one-fifth of the whole diameter. Isolated stem-joints of a similar character and size occur in the collection from the same horizon B (K 23·262) associated with crowds of *Pleurotomaria umariensis,* and the same occur on horizon D (K 23·264).

Rhombopora sp.

Pl. 34, fig. 17.

One small fragment of a slender rod-like cylindrical bryozoan measuring about 2 mm. in length and less than 1 mm. in diameter has been recognised amongst the crumbling fragments off a large piece of rock (K 21·125). The specimen may be referred to the genus *Rhombopora* and shows on the semi-circumference exposed a few (4 or 5) rather irregular longitudinal rows of alternating large oval cell-apertures of equal size separated by rather thick rounded interapertural ridges widening below the apertures and bearing a few small spinose tubercles somewhat irregularly distributed, but usually there seems to be one below each aperture.

This zoarium resembles *Rhombopora nicklesi* Ulrich [1] from the Lower Coal measures of Illinois rather than *Rhabdomeson rhombiferum* (Phill.) [2] with which Ulrich compares this American species. Loczy [3] has figured a specimen from Teng-tjan-tsching as *Rhabdomeson* cf. *rhombiferum* which appears to possess most of the characters of our specimen, though he says that the edges of the cells are sharp and smooth. *Rhomb. Wortheni* Ulrich [4] from the Lower Carboniferous of America, *Rhomb. lepidodendroides* Meek, and *Rhomb. bigemmis* Keys. are other allied species. *Rh. tenuis* Hinde [5] from the West Australian Carboniferous may also be compared.

Productus umariensis sp. nov.

Pl. 31, figs. 1-6.
Pl. 32, figs. 4-8.

[1] Ulrich, *Geol. Surv. Illinois,* VIII, 1890, p. 661, pl. LXX, figs. 1, 1a-e.
[2] Phillips, *Geol. Yorkshire,* pl. I, figs. 34, 35.
[3] Loczy, *Beschr. Palaeont. Stratig. Result.,* Reise Bela Szechenyi in Ostasien, 1898, p. 97, t. III, fig. 22.
[4] Ulrich, *Journ. Cinnc. Soc. Nat. Hist.,* Vol. IV, 1884, p. 32, pl. 1, figs. 4, 4a, b.
[5] Hinde, *Geol. Mag.,* Dec. 3, Vol. III, 1890, p. 203, pl. VIIIA, pp. 4, 4a.

Shell transversely semielliptical to subquadrate, wider than long; hinge-line long, straight, equal to or slightly less than maximum width of shell; cardinal angles subrectangular to slightly obtuse, not produced; valves closely appressed. Pedicle-valve gently convex. not inflated, horizontally extended in cardinal region, but arched down slightly at sides and in front; body feebly convex, sometimes rather flattened in middle, sloping down gradually to depressed triangular horizontal ears which are occasionally slightly arched along the hinge-line and upturned at the cardinal angles, but are not sharply marked off from the body; hinge-line with more or less developed thickened band along its edge forming a narrow smooth false hinge-area set at right angles to the plane of the valve and usually bearing inside its edge 1-3 stout, short, straight, hollow spines, obliquely directed outwards and upwards; beak low, broad, obtuse, rounded, very slightly incurved or elevated, scarcely or not at all projecting beyond hinge-line.

Surface of pedicle-valve covered with numerous fine rounded radial riblets usually straight and of equal size and thickness, 8-10 occurring in a space of 5 mm. at a distance of 15 mm. from the beak, and increasing in number by intercalation at about one-third to one-half their length and occasionally again nearer the margin, but sometimes with a few riblets thicker than the rest for all or part of their length or as far as the base of a spine where they divide into 2-3 smaller riblets which rapidly become as thick as the others. Spine-bases on body very few and irregularly distributed, usually on the thicker riblets, sometimes more numerous in umbonal region than elsewhere. Intercostal grooves rounded, as wide or rather wider than riblets. Whole surface of shell covered with a close fine concentric striation, and having a few inconspicuous low weak rounded rugae mostly developed on the ears and posterior slopes of the body. Interior of pedicle-valve with large flabellate radially striated diductors weakly marked, extending fully half the length of the valve, having more deeply impressed posterior stalks embracing a narrow adductor scar and bounded by coarsely pitted ovarian areas on each side at base of ears. Brachial valve deeply concave, closely appressed to opposite valve, with ears more clearly marked off from body and having a gentle independent convexity; surface covered with riblets similar to those on opposite valve, but usually increasing in number by bifurcation more than by inter-

calation. Interior with low median septum extending about half the length of the valve.

Dimensions	I.	II.	III.	IV.	V.	VI.
Width . . .	37	35	40	40	43	34 mm
Length . . .	28	27	27	30	34	27 mm
Depth	10	..	8	12	15	13 mm

Remarks.—This species is by far the most abundant fossil in the shell-band, and it frequently forms the bulk of the rock. Detached specimens free from matrix, though rarely perfect, also occur in the later collection made by Mr. Gee. The species varies slightly in the convexity of the pedicle-valve and in the degree of elevation and overhang of the beak, but the convexity is never strong nor the beak swollen, and the general flatness and horizontal extension of the valve without any marked anterior curvature downwards are characteristic features; the presence of occasional stronger riblets and of scattered spine-bases on the surface are also typical.

Its affinities were at first thought to be with *Pr. hemisphericus* Sow.[1] of the Lower Carboniferous, and Krenkel[2] has given a figure of this species from the Tian-Shan which considerably resembles some of our shells. Davidson (op. cit.) regarded *Pr. hemisphericus* as merely a variety of *Pr. giganteus* Mart., and depicted a large number of small spines along the cardinal edge, to which feature Vaughan[3] also alludes. The latter author in noticing its close relations to *Pr. cora* (auctt.) distinguishes it by the more gradual slope of the sides, the broader and less arched beak and the stronger cylindrical rolling of the wings, as well as by the more transverse shape of the shell. Some of the shells from the Cora and Schwagerina horizons of the Urals attributed by Tschernyschew[4] to *Pr. cora* bear a great resemblance to our species in their general shape, slight convexity, small projection of the beak, thickened cardinal margin and supra-cardinal spines, but we may doubt if these Russian shells belong to the same species as the true South American *Pr. cora* D'Orb. The synonymy of this species is still a

[1] Davidson, Mon. Brit. Carb. Brach. (Palæont. Soc.), Vol. II, p. 144, pl. XL, fig. 4-9.

[2] Krenkel, *Abh. bayer Akad. Wiss.*, Math. Phys. Kl., XXVI, Abh. 8, 1913, p. 41, t. II, fig. 1.

[3] Vaughan, *Quart. Journ. Geol. Soc.*, Vol. LXI, 1905, p. 291, pl. XXV, fig. 5.

[4] Tschernyschew, *Mem. Com. Geol. Russ.*, Vol. XVI, No. 2, 1902, pp. 279, 621. t. XXXIII, figs. 2, 3, t. XXXV, fig. 1, t. LIV, figs. 1-5.

matter of controversy [1]. We may also draw attention to the similarity of the figure of a shell from the Carboniferous of Yunnan attributed by Mansuy [2] to *Pr. cora*, while one from Cambodia [3] attributed by him to *Pr. lineatus* (which is often included in *Pr. cora*) has the same kind of ears, riblets and cardinal spines as our species, but possesses a more inflated body and more overhanging beak.

With regard to North American shells which have been referred to *Pr. cora* from various horizons in the Carboniferous or Permo-Carboniferous, some of them bear a considerable resemblance to our Umaria shell, especially some of the shells figured by Girty [4] from the Wewoka Formation of Oklahoma as *Pr. cora*, for they have the spiniferous riblets larger and more prominent than the rest. But we may particularly compare the shell figured by Hall and Clarke [5] as *Pr. auriculatus* Swallow, from the Coal Measures of Missouri, which in shape, ribbing and cardinal spines appears to be closely similar. The species termed *Pr. magnus* Meek and Worthen,[6] from the Keokuk of Illinois, seems also to have many features in common.

Amongst Australian shells referred to *Pr. cora* we may compare the variety *farleyensis* Eth. and Dun,[7] from the Lower Marine stage of New South Wales.

But it seems inadvisable to include our shells in the very varied assemblage of forms referred to *Pr. cora*, and a new specific name seems fully justified.

It may be mentioned that certain figured examples of *Pr.* (*Marginifera*) *vihiana* Diener [8] from the Zewan Beds of Kashmir, lacking a median sinus, seem to resemble *Pr. umariensis* in shape and general characters, but the latter cannot be referred to this subgenus.

[1] Hayasaka, *Science Rept. Tohoku Imper. Univ.*, *Ser.* 2, Geol., Vol. VI, No. 1, 1922, pp. 86-93.

[2] Mansuy, *Mem. Serv. Geol. Indo-Chine*, Vol. I, fasc. 2, 1912, p. 95, pl. XVII, fig. 9.

[3] *Ibid*, Vol. III, fasc. 3, 1914, p. 18, pl. VI, figs. 2a-c.

[4] Girty, *Bull.* 544, *U. S. Geol. Surv.*, *1915*, p. 68, pl. VIII, figs. 4, 5 (non 6).

[5] Hall and Clarke, *Palaeont. New York*, Vol. VIII, Brach. 1, 1892, pl. XVIIA, fig. 24.

[6] Meek and Worthen, *Geol. Surv. Illinois*, III, 1868, p. 528, pl. XX, fig. 7.

[7] Etheridge and Dun, *Rec. Geol. Surv. N. S. Wales*, Vol. VIII, pt. 4, 1909, p. 302, pl. XLII, figs. 9-11.

[8] Diener, Anthrac. Faunae Kashmir, etc., *Pal. Indica*, N. S. Vol. V, pt. 2, 1915, p. 79, pl. VIII, figs. 10-12.

Productus umariensis var. *spinifera*.

Pl. 33, figs. 1-6.
Pl. 35, fig. 9.

Shell transversely subquadrate; hinge-line equal to or rather less than maximum width of shell. Body of pedicle-valve gently convex; beak rather small, not swollen, scarcely incurved, very slightly projecting behind; ears somewhat flattened, large, not sharply marked off from body but possessing a cardinal curvature; cardinal angles subrectangular or obtuse; cardinal margin more or less thickened and bearing above its edge 2-3 large stout hollow spines directed outwards and backwards nearly in plane of valve, with a few smaller spines on posterior slopes of umbo. Surface of valve covered with regular sub-equal rounded riblets occasionally swelling up into hollow spine-bases which are usually arranged in an open quincunx order, 6-10 riblets apart; each riblet beyond its spine-base divides into 2 or 3 smaller riblets which ultimately become as large as the others. Concentric rugae strong on ears, but weaker and narrower on body, meeting hinge-line at obtuse angle.

Dimensions.—Width 20-40 mm.

Remarks.- This variety seems only separable from the typical *Pr. umariensis* by the greater abundance and more regular distribution of spine-bases on the body. It is much like some specimens of *Pr. cancrini* Kut. as figured by Netschajew [1] from the Permian of Russia, but it is not like typical examples of that species. A shell from the Wewoka Formation of Oklahoma which Girty [2] described and figured as "an unusual form of *Pr. cora*" bears also a considerable resemblance. Some of the shells attributed to *Pr. cancriniformis* Tschern. by Diener [3] from Chitichun and by Schellwien [4] from the Trogkofel show many points of similarity, judging from the published figures. *Pr. pertenuis* Meek, which Girty [5] says is intimately related to *Pr. cora*, is also apparently allied, and it is specially mentioned by Tschernyschew [6] and Diener as much resembling *Pr. cancriniformis*. But the typical specimens of *Pr. cancriniformis* are much narrower, more elongated and more swollen,

[1] Netschajew, *Mem. Com. Geol. Russ.*, N. S., Livr. 61, 1911, p. 138, t. III, figs. 2-5.
[2] Girty, *Bull.* 544, *U. S. Geol. Surv.*, *1915*, p. 68, pl. VIII, fig. 6 (non 4, 5).
[3] Diener, Himal. Foss., Vol. I, pt. 3, (*Pal. Indica* Ser. XV), p. 25, pl. IV, fig. 6.
[4] Schellwien, *Abh. k. k. geol. Reichsanst.*, XVI, 1900, p. 43, t. IX, figs. 1-3.
[5] Girty, *op. cit.*, p. 75, pl. VIII, figs. 3, 3a.
[6] Tschernyschew, *Mem. Com. Geol. Russ.*, XVI, 1902, pp. 292, 629, t. III, fig. 5.

and are quite unlike the Umaria shell. The American species *Pr. pratteniamus* Norwood[1] which some authors[2] consider inseparable from *Pr. cora,* includes some shells[3] which seem to be identical in general characters with our Umaria form, but are quite distinct from the typical *Pr. cora.* The division of the riblets anterior to the base of the spines on the general surface of the shell is similar to that figured and described by Weller in an allied American species named *Pr. fernglenensis* Weller[4], from the Kinderhook Group of Illinois, and it seems to be rather a peculiar and characteristic feature.

The increased number of spines on the body is the only feature by which we can satisfactorily separate our variety from the typical *Pr. umariensis,* and there are some transitional forms in the collection. It occurs in the shell-band and on horizons A, B and C. One specimen from horizon C (K 23·263) which is here figured (Pl. 35, fig. 9) differs from the typical *spinifera* by having an unusually short hinge-line and a sub-circular rather than transverse outline to the shell, but in other respects it does not seem to show any features by which we can separate it.

Productus rewahensis sp. nov.

Pl. 32, figs. 1, 1a.
Pl. 35, figs. 1-7.

Shell transversely subquadrate to semi-elliptical, wider than long; hinge-line equal to or rather greater than width of shell. Pedicle-valve convex, more or less inflated, rounded; beak broad, obtuse, rounded, swollen, somewhat overhanging and projecting beyond hinge-line; ears rather large, triangular, rarely subacute and projecting, depressed, but not sharply marked off from the swollen body which rises with a marked independent convexity from them. Surface of valve covered with fine regular equal or subequal rounded thread-like non-spiniferous riblets increasing in number by intercalation once or twice, and numbering about 16 in a space of 10 mm.

[1] Norwood, *Journ. Acad. Nat. Sc. Philad.*, III, 1854, p. 17, fig. 10.
[2] Schuchert, *Bull.* 87 *U. S. Geol. Surv.*, 1897, p. 322.
[3] Meek, *Final Rept. Geol. Surv. Nebraska*, 1872, p. 163, pl. 8, figs. 10a, b (non cet.).
[4] Weller, *Mon. I, State Geol. Surv. Illinois*, 1914, p. 106, pl. IX, figs. 11-17.

at a distance of 10 mm. from the beak. Hinge-line occasionally thickened and furnished with 2-4 supramarginal spines.

Dimensions.	I.	II.	III.	IV.	V.
Length	27	26	26	33	28 mm
Width	34	34	29	44	30 mm
Depth	13	13	12	15	17 mm

Remarks.—This shell which occurs on all the horizons varies somewhat in its proportions, some specimens being wider than others. It appears to be allied to the Russian species *Pr. Tschernyschewi* Netsch.[1], of Permian age, but differs chiefly in being less globose, shorter and more transverse, as well as in the ears being larger and rather more distinctly separated from the body and in the riblets being rather coarser. From *Pr. umariensis* it differs in the more inflated overhanging and broader beak, in the more convex and swollen body, in the greater regularity, larger number and smaller size of the riblets and in the absence of spines upon them. But it is sometimes difficult to separate the two local species, and for a long time there was hesitation in regarding them as specifically distinct. Another Russian species *Pr. planohemisphaerium* Netsch.[2] has more enrolled ears, but otherwise seems to be allied, and *Pr. latus* Netsch.[3] also shows many similar features. The shells from Chitichun which Diener[4] referred to *Pr. lineatus* Waag. bear a certain resemblance in general characters to our shell, and we may also note its similarity to the shell from the Zewan Beds of Kashmir which Diener[5] identified with *Pr. waagenianus* Girty,[6] a North American Guadelupian species closely allied to *Pr. eucharis* Girty,[7] from the Upper Carboniferous of Idaho.

In the collection from band (K 23·264) at Umaria there is one interior of a brachial valve (Pl. 35, fig. 6) showing an inner pair of short straight low very slightly divergent median ridges, and an outer pair of slightly arched strongly divergent rather longer and more elevated ridges bisecting the angle between the hinge-line and

[1] Netschajew, *Mem. Com. Geol. Russ.*, N. S., Livr. 61, 1911, p. 141 t. I, figs. 5, 7, t. II, figs. 6-11.
[2] *Ibid.*, p. 141, t. VI, fig. 6.
[3] *Ibid.*, p. 142, t. II, figs. 12, 13.
[4] Diener, *Pal. Indica*, Ser. XV, Vol. I, pt. 3, p. 14, pl. IV, figs. 2-5.
[5] Diener, Anthrac. Fauna of Kashmir, etc., (*Pal Indica*, N S, Vol. V, Mem. 2, 1915), p. 71, pl. VI, figs. 18, 19, pl. VII, fig. 6.
[6] Girty, *Prof. Paper* 58, *U. S. Geol. Surv.*, 1908, p. 253, pl. XII, figs. 6, 7.
[7] Girty, *Bull.* 436, *U. S. Geol. Surv.*, 1910, p. 28, pl. II figs. 3, 4.

the inner pair of ridges. A sharply curved narrower and lower brachial ridge of the usual type can be detected on the left side, but the corresponding one on the other side is not preserved. It is probable that this specimen belongs to *Pr. rewahensis* rather than to *Pr. umariensis*, for the valve is more deeply concave and more rounded and the beak is broader and more obtuse and the ribbing finer than in the latter species. The internal cast of a pedicle-valve (Pl. 35, fig. 7) from the same band D (K 23·264) shows the flabellate diductors subcentrally divergent and with rather long parallel posterior stalks between the bases of which lie the narrow conjoint adductor impressions.

Productus rewahensis var. *coroides.*

Pl. 32, figs. 2, 2a, 3, 3a.
Pl. 35, figs. 8, 8a.

Shell subquadrate in shape, as long as wide; hinge-line rather less than maximum width of shell; cardinal angles not produced. Pedicle-valve swollen, rounded, convex, arching down uniformly at front and sides; beak very broad, rounded, swollen, obtuse, overhanging hinge-line; ears small, subtriangular, slightly enrolled and pointed but not produced, not flattened. scarcely marked off from body; hinge-line with 2-3 short blunt sub-marginal spines. Surface ornamented with numerous fine rounded radial equidistant nonspiniferous riblets of equal or subequal size, increasing in number by intercalation and occasional bifurcation, 20-25 riblets occurring in a space of 10 mm. at a distance of 10 mm. from beak. Concentric growth-ridges few, low, broad, inconspicuous or absent except in ears.

Dimensions.	I (Pl. 35, fig. 8)	II.	III.
Length	34	38	36 mm
Width	32	39	35 mm
Height	22	—	—

Remarks.—This variety, of which the best example is the specimen figured on Plate 35, fig. 8, seems almost indistinguishable from some of those figured by Netschajew (op. cit.) as *Pr. Tschernyschewi* and differs from the typical *Pr. rewahensis* above described by its more subquadrate shape and relatively shorter hinge-line. Some

shells from the Pennsylvanian of Colorado which Girty[1] figures as *Pr. cora* bear a considerable resemblance, and *Pr. altonensis* Norw. and Pratt.[2] from the Lower Carboniferous of Illinois may also be compared.

Spirifer narsarhensis sp. nov.

Pl. 33, figs. 7, 7a, 7b.
Pl. 36, figs. 1-4.
variety { Pl. 33, figs. 8-10.
Pl. 36, fig. 5.

Shell transversely semielliptical to rounded subtriangular, with cardinal angles slightly rounded or obtuse and hinge-line slightly less than maximum width of shell. Pedicle-valve subtriangular, moderately convex; sinus rounded, usually shallow, well defined, continuous from beak to anterior margin with narrow more or less flattened floor often occupied by a weak median riblet, and having its more or less flattened steep sides bordered by the first lateral ribs which may or may not divide unequally at about one-third to one-half their length, the smaller inner half forming a weak narrow riblet on the side of the sinus; beak high, pointed, prominent, incurved, with concave rounded umbonal shoulders; hinge-area high, concave, triangular, lying nearly in plane of valve or gently inclined to it, striated parallel to hinge-line. Lateral lobes with 6-8 strong prominent sharply rounded or subangular ribs on each side, successively decreasing in size and strength to cardinal angles, some or most of them bifurcating unequally near their distal extremities; interspaces subangular or angular, as wide as ribs. Brachial valve rather more convex than opposite valve; beak much lower and smaller, and hinge-area much lower and narrower; surface of valve with suddenly elevated strong subquadrate median fold rather slowly widening anteriorly, flattened and grooved along the middle of its narrowed top, and having a thin weak riblet (rarely two riblets) for most of its length on each lateral slope. Lateral lobes with 6-7 ribs on each side similar to those on opposite valve, some or all of them bifurcating near their distal ends. Surface of both valves covered with strong subequidistant imbricating concentric

[1] Girty, *Prof. Paper* 16, *U. S. Geol. Surv.*, 1903, p. 364, pl. IV, figs. 3, 4.
[2] Weller, *op. cit.*, 1914, p. 124, pl. X, figs. 14-24.

lamellae crossed by a very delicate close radial striation. Interior without septa or dental plates.

Dimensions.

Width (max.)	21 mm.
Length „	17 mm.

Remarks.—There is one good complete specimen (Pl. 33, figs. 7, 7a, 7b) of this species in the first collection from Umaria (K 21·425) and three complete but poorly preserved specimens from horizon B (K 23·262) in the second collection, as well as many separate pedicle-valves, some of which show the interior. There is a noticeable variation in the development and number of bifurcated ribs on the lateral lobes, some examples having nearly all the ribs simple, and the riblets in the sinus and in the fold also vary slightly in development and strength. The minute radial striation on the surface is rarely visible, but the concentric lamellae are always conspicuous.

The generic reference of this shell has been a matter of some doubt because of its resemblance in shape and ribbing to certain species of *Spiriferina* in spite of the absence of an internal median septum in the pedicle-valve. The general characters at first led to its reference to *Spiriferina*, and it was provisionally considered to belong to *Sp. octoplicata* Sow., for in the occasional bifurcating lateral ribs it particularly resembles the variety *biplicata* Dav.[1] of the British Lower Carboniferous and the Russian Lower Permian.[2] But the typical *Sp. octoplicata*[3] has fewer lateral ribs and an angulated median fold. The typical form of the allied species *Sp. perplicata* North[4] has also an angular fold, and there are no bifurcated ribs on the lateral lobes nor any riblets in the sinus or on the sides of the fold. In the presence of these riblets we may note a resemblance to *Sp. cambodgiensis* Mansuy[5] from the Permo-Carboniferous of Indo-China, and the shape of the shell and of its sinus and fold are closely similar, but in Mansuy's species all the ribs are simple and usually fewer in number, and Colani[6] has remarked that it appears to connect several species. It may be mentioned that although *Sp. cristata* (Schloth.) (of which *Sp. octoplicata* is often

[1] Davidson, *Mon. Brit. Foss. Brach.*, Vol. II, Appendix, p. 226, pl. LII, figs. 11-13.
[2] Fredeiks, *Rec. Geol. Comm. Russ. Far East*, No. 28, 1924, p. 35, t. I, fig. 15.
[3] North, *Quart. Journ. Geol. Soc.*, Vol. LXXVII, 1920, p. 215, pl. XIII, figs. 8, 9.
[4] *Ibid.*, p. 219, pl. XIII, figs. 7a-c, 10.
[5] Mansuy, *Mem. Serv. Geol. Indo-Chine*, Vol. II, fasc. 4, p. 119, pl. XIII, fig. 6; *ibid.*, Vol. III, fasc. 3, p. 24.
[6] Colani, *Bull. Serv. Geol. Indo-Chine*, Vol. VI, fasc. 5, 1919, p. 13, pl. I, figs. 3a-c.

regarded as only a variety) has usually an angular sinus devoid of any riblets, yet Davidson records their occasional presence in some British Carboniferous examples, and we also find a riblet in some specimens [1] of *Sp. duodecimcostata* McCoy from the Carboniferous of Queensland. We cannot, however, fail to notice in our Umaria shells many features which are possessed by some of the shells referred by Davidson [2] to *Spirifer grandicostatus* McCoy, such as the shape of the shell, the bifurcation of some of the lateral ribs and the presence of riblets on the fold and in the sinus. Tschernyschew [3] believed that *Sp. rectangulus* Kut. from the Upper Carboniferous of Russia, was closely allied to *Sp. grandicostatus*, but none of his figured specimens much resemble our Umaria form. The latter is more like some specimens attributed by Licharew [4] and Netschajew [5] to *Spirifer Blasii* De Vern. from the Russian Permian, which is admitted to be a very variable species, but Mansuy's [6] variety of it from the Permian of Yunnan is quite different. *Spirifer Leidyi* Norw. and Pratt.,[7] of the Chester Limestone of North America, bears a much greater resemblance in its shape, ribbing and ornamentation, than any of the above mentioned, and *Sp. pellaensis* Weller [8], also from the Lower Carboniferous of North America, is another allied species. But our species has a less strongly divided median fold in the brachial valve than *Sp. Leidyi*, and its lateral ribs are more commonly bifurcated. There is a species from the Fenestella Series of Kashmir described by Diener as *Spirifer Middlemissi* [9] and regarded as closely allied to *Sp. grandicostatus* McCoy, which is almost indistinguishable from our Umaria form. But the fold is stated to be divided by three principal ribs of which the central one is the largest, instead of the fold having a median groove, though the occasional bifurcation or trifurcation of the 7-10 lateral ribs and the lamellose character

[1] De Koninck, Descr. Palæoz. Foss. N.S. Wales (transl. E. David), *Mem. Geol. Surv. N.S. Wales, Palæont.* No. 6, 1898, p. 182, pl. XII, fig. 4 and footnote.

[2] Davidson, *op. cit.*, pp. 33, 222, pl. VII, figs. 7-16.

[3] Tschernyschew, *op cit.*, 1902, p. 545, t. VIII, fig. 1, t. XLI, figs. 1-5.

[4] Licharew, *Mem. Com. Geol. Russ.*, N. S., Livr. 85, 1913, p. 54, t. III, figs. 9, 11.

[5] Netschajew, *ibid.*, Livr. 61, 1911, p. 82, t. XII, figs. 9, 10.

[6] Mansuy, *Mem. Serv. Geol. Indo-Chine*, Vol. I, fasc. 2, 1912, p. 114, pl. XXII, figs. 2a-e.

[7] Norwood and Pratten, *Journ. Acad. Nat. Sc.,Philad.*, III, 1854, p. 72, pl. 9, fig. 2; Weller, *op. cit.*, 1914, p. 345, pl. XLVII, figs. 17-31.

[8] Weller, *op. cit.* 1914, p. 340, pl. XLV, figs. 1-31.

[9] Diener, Anthrac. Faunae of Kashmir, Kanaur and Spiti. *Pal., Indica*, N. S., Vol. V, Mem. 2, 1915, p. 41, pl. IV, figs. 9-12,

of the test agree precisely with our new species. The sinus in the pedicle-valve of *Sp. Middlemissi* is said to be narrow and to be divided by one or two longitudinal ribs, and in the allied species *Sp. Varuna* Diener,[1] these ribs are more numerous, and Diener mentions its resemblance to *Sp. Blasii.* The reduction in the angularity and number of the lateral ribs, their simplicity and the more rounded outline of the shell lead us by intermediate forms (Pl. 33, figs. 8-10, Pl. 36, fig. 5) to the fairly distinct variety described below.

On the whole the affinities of *Sp. narsarhensis* are more with *Sp. grandicostatus*, *Sp. Middlemissi* and *Sp. Leidyi* than with any others.

Spirifer narsarhensis var. *pauciplicata.*

Pl. 33, fig. 11.
Pl. 36, figs. 6, 7.

Shell transversely oval to elliptical; cardinal angles well rounded, hinge-line less than maximum width of shell. Pedicle-valve gently convex, more so than opposite valve; beak scarcely elevated above hinge-line, incurved; hinge-area small, low, triangular, concave, steeply inclined to plane of valve; median sinus rounded, deep, with steeply sloping sides and narrow flat floor, usually without a weak median rounded riblet and rarely with a shorter narrower lateral one on each slope; lateral lobes with 4-7 rounded or slightly subangular strongly elevated simple ribs decreasing successively in size towards the cardinal angles (near which they are occasionally obsolete) and separated by wide rounded interspaces as wide as or wider than the ribs. Brachial valve with subquadrate narrow high median fold suddenly elevated, more or less flattened on top rarely grooved and not wider than two of the adjacent ribs, rarely having weak narrow riblets on its steep slopes; lateral lobes with 4-7 ribs on each side similar to those of opposite valve; beak small, obtuse, low. Surface of shell covered with strong regular concentric overlapping lamellae, usually equidistant, and crossed by very delicate radial striation.

Dimensions.	Brachial valves.		
	I.	II.	III.
Length	13·0	9·5	17·0 mm.
Width	18·5	16·0	24·0 mm.

[1] *Ibid.*, p. 43, pl. 34, figs., 13-15.

Remarks.—As above remarked this variety is connected with the typical *Sp. narsarhensis* by passage-forms. But in extreme examples the ribs are further apart, wider and fewer in number, the shell is more rounded and elliptical in shape, and the ribs are always simple, so that certain forms seem sufficiently different to deserve a varietal name (*pauciplicata*) though they occur associated with the type of the species in the same beds. Mr. E. R. Gee has collected a considerable series of specimens, mostly of isolated valves, from horizon B, and they are in several cases in a good state of preservation. It seems as if this variety were more like *Spirifer bifurcatus* Hall,[1] than *Sp. Leidyi* Norw. and Pratt., though Schuchert [2] put them as synonyms. The original example from Umaria (Pl. 33, fig. 11) was much crushed and imperfect and was at first identified as *Spiriferina cristata* Schloth.

Reticularia barakarensis sp. nov.

Pl. 34, figs. 1-9, 10 ?

Pl. 36, figs. 8-11.

Shell subcircular to transversely subelliptical, gently biconvex; hinge-line short, less than width of shell. Pedicle-valve moderately convex, with strong rounded broad median sinus extending from the beak to the anterior margin increasing in width, well defined by low sharply rounded edges or weak folds and having rather steep sides and the floor projecting in front as a short rounded tongue; beak rather suddenly elevated, small, high, prominent, acutely pointed, sharply incurved, with sides somewhat excavated and diverging at less than 90°; delthyrium triangular, open; hinge-area gently concave, triangular, not sharply defined at sides. Interior of pedicle-valve with straight or slightly arched thin dental plates, scarcely divergent and extending about one third the length of the shell. Brachial valve with low median rounded fold and small inconspicuous beak. Surface of valves covered with narrow regular closely-placed thin concentric lamellae of fairly equal width covered with a dense felt of closely placed minute radial equidistant hollow flattened recumbent spinules usually alternating on successive lamellae and resulting in a regular fimbriation of surface

[1] Weller, *op. cit.*, p. 346, pl. XLVII, figs. 6-16.
[2] Schuchert, *Bull.* 87, *U. S. Geol, Surv.*, 1897, p. 395.

in the middle part of the valves but radially arranged on the flanks and thus giving in these parts the appearance of radial lineation.

Dimensions.	I.	II.
Length	30	28 mm.
Width	32	30 mm.

Remarks.—The true reference of this fossil was a matter of much difficulty in the case of the first specimens submitted to me, as only broken valves or impressions of parts of the surface were available, and the appearance of the ornamentation differs much according to the state of preservation and its position on the shell. In cases where the shell is rubbed the surface looks as if it were pitted, the spaces left by the spine-bases forming minute lanceolate or oval pits. Most of the specimens are crushed or distorted, but the further material obtained by Mr. E. R. Gee from Horizon B is in a better state of preservation, so that the external characters of the species can be quite satisfactorily determined.

The resemblance of this shell to many of those referred to *Spirifer lineatus* Mart., such as that one described and figured by De Koninck[1] from the Permo-Carboniferous of New South Wales, is at once apparent. But the typical *Sp. lineatus* Mart. of the European Lower Carboniferous and the shells from the Productus Limestones of the Salt Range referred to that species by Waagen,[2] are quite different, the broad median sinus in the pedicle-valve of our form being particularly noticeable and distinctive. There has been much latitude in the use of the specific name *lineatus*, and the species has been frequently recorded from Upper Carboniferous or Permian beds in Asia[3] and elsewhere, though we may doubt the accuracy of all the identifications. Thus the American shell *Squamularia perplexa* McChesney[4] has frequently been mistaken for it in the past, being externally not unlike many of the shells referred to Martin's *Reticularia lineata*, but Girty[5] is led to believe that *Squamularia* has no internal plates and thereby is generically separable from

[1] De Koninck, Palæoz. Foss, New South Wales (transl. by Edgeworth David) *Mem. Geol. Surv., N. S. Wales*, Palæont. No. 6, 1898, p. 174, pl. XI, fig. 9.

[2] Waagen, Salt Range Foss. I, (*Pal. Indica*, Ser. XIII), p. 540, pl. XLII, figs. 6-8.

[3] Broili, *Perm. Brach. Timor* (*Paläont. Timor*, Lief. VI, Abt. XII, 1916), p. 40, t. 121, figs. 4, 6-8, t. 122, figs. 1-16; Hayasaka, *Science Rept. Tohoku Imper. Univ.*, Ser. 2, Geol., Vol. VIII, No. 1, 1924, p. 51, pl. VI, figs. 15, 16.

[4] Girty, *Bull.* 544, *U. S. Geol. Surv.*, 1915, p. 92, pl. XI, figs. 1-3a.

[5] Girty, *in* Willis and Blackwelder '*Research in China*', (*Carnegie Instit.*), Vol. III 1913, pp. 300, 322.

Reticularia. The resulting confusion has been recently mentioned by the present author [1] in describing specimens from the Upper Carboniferous of Chitral, and Girty,[2] Buckman,[3] Hayasaka [4] and other writers in late years have alluded to the difficulty of separating the many forms or varieties grouped under the designation *Sp. lineatus*, and there is little agreement in their views. Thus Hayasaka (op. cit.) considers that one of the distinguishing features of *Squamularia* is the possession of a ventral sinus which is absent in *Reticularia.* But this does not conform with Davidson's opinion, for he included the sinuated *Sp. mesoloba* Phill. in *R. lineata.* Girty and Kozlowski [5] likewise differ. It should be also mentioned that though Waagen [6] states that *Reticularia* has no dental plates, Girty regards their presence in this genus as the important and critical character distinguishing it thereby from *Squamularia.* Frederiks,[7] however, includes Broili's examples of *R. lineata* from the Permian of Timor in his synonymy of *Squamularia perplexa* McChesney. The examples of *R. lineata* figured by Diener [8] from the Himalayas or those of this species and its allies figured by Mansuy [9] from the Productus Limestone of Indo-China do not represent a shell identical with the present one from Umaria. The Russian species *R. rostrata* (Kut.) [10] is also different, but the Sicilian *R. affinis* Gemm. with which Diener [11] ultimately compared some of the Chitichun specimens, bears more resemblance to our form.

There is a shell from the Carboniferous Limestone of Ireland which McCoy named *Reticularia reticulata* [12] which agrees with our shell in the presence of a median fold and sinus, as well as in the general ornamentation of the surface, but it cannot be considered

[1] Reed, Upper Carb. Foss. Chitral, (*Pal. Indica*, N.S. Vol. VI, Mem. No. 4, 1925), p. 83.
[2] Girty, *Prof. Paper* 58, *U. S. Geol. Surv.*, 1908, p. 366.
[3] Buckman, *Quart. Journ. Geol. Soc.*, LXIV, 1908, p. 33.
[4] Hayasaka, *op. cit.*, Vol. VI, No. 1, 1922, p. 129.
[5] Kozlowski, *Annales de Paléont.* IX, 1914, p. 73, text fig. 18.
[6] Waagen, Salt Range Foss. I, (*Pal. Indica.* Ser. XIII), pp. 538, 540, pl. XLII, figs. 6-8.
[7] Frederiks, *Rec. Geol. Comm. Russ. Far East*, No. 28, 1924, I, Brach., p. 47.
[8] Diener, Himal. Foss. (*Pal. Indica*, Ser. XV), Vol. I, pt. 3, 1897, p. 57, pl. IX, figs. 5-8.
[9] Mansuy, *Mem. Serv. Geol. Indo-Chine*, Vol. II, fasc. 4, 1913, pp. 80-82, pl. IX, figs. 1-3.
[10] Tschernyschew, *Mem. Com. Geol. St. Petersb.*, XVI, 2, 1902, pp. 194, 575, t. XV, figs. 4, 5; t. XX, figs. 14-18.
[11] Diener, *op. cit.*, Vol. I, pt. 5, 1903, p. 19.
[12] McCoy, *Syn. Carb. Foss. Ireland*, 1844, p. 143, pl. XIX, fig. 15.

identical. The typical *R. imbricata* Phill.[1] from the Carboniferous Limestone of Yorkshire, is also closely similar in external characters. But Davidson [2] regarded the Irish species as a synonym of *R. lineata* Mart. and the Yorkshire one as being merely of varietal rank.

With greater success we may compare our Umaria species is more comparable with *R. setigera* Hall,[3] and to a lesser degree with *R. pseudolineata* Hall [4] and *R. salemensis* Weller [5] from the Lower Carboniferous of the United States than with any of the foregoing species.

Reticularia barakarensis var. *subplicata.*

Pl. 36, figs. 12, 13.

Shell transversely elliptical. Pedicle-valve gently convex, having a shallow broad rounded median sinus rapidly increasing in width anteriorly with its floor somewhat flattened and bearing a faint narrow median groove and projecting as a short rounded tongue. On each side of the sinus a low broad rounded radial fold occupies nearly half of each lateral lobe, and there is a second similar but narrower and weaker radial fold outside it occupying half the remaining space to the cardinal margin, the folds being marked off by shallow sharply impressed slightly curved radial grooves; beak small, low, rising a little above hinge-line, acutely pointed, incurved. Surface of shell covered with numerous thin concentric lamellæ having short adjacent recumbent radial spinules producing a minute fimbriation and lineation.

Dimensions.

Length	31 mm.
Width	38 mm.

Remarks.—This variety (of which there is only one good specimen showing the lateral radial folds and another crushed one with the folds scarcely discernible, both from Horizon B, K 23·262) differs from *R. barakarensis* not only by the presence of these lateral folds but also by the shallower less sharply defined grooved sinus, the

[1] Phillips, *Geol. Yorkshire*, 1836, p. 219, pl. X, fig. 20.

[2] Davidson, *Brit. Foss. Brach.*, Vol. II, 1857, p. 62, pl. XIII, figs. 11-13; *ibid.*, Vol. IV, pt. 3, 1880, p. 275.

[3] Hall and Clarke, *Palæont. New York*, VIII, Brach. II, pl. 36, figs. 26, 27. Weller, *op. cit.*, 1914, p. 131, pl. LXXIV, figs. 12-22. Girty, *Bull. 593, U. S. Geol. Surv.*, 1915, p. 65, pl. IV, fig. 6.

[4] Hall and Clarke, *op. cit.*, pl. 36, figs. 28, 30.

[5] Weller, *op. cit.*, 1914, p. 433, pl. LXXV, figs. 15-19

more transverse shape of the shell and the lower and smaller beak to the pedicle-valve. The ornamentation seems to be identical. The presence of a sinus and median fold with a few broad rounded lateral radial folds with a similar shape to the shell are found in *Reticularia fimbriata* Conr.[1] of the Devonian, and Miss Muir Wood has recently described a Lower Carboniferous species from Yorkshire under the name *R. lobata*[2] having the same general characters. Apart from the ornamentation of the surface, the young example of *Sp. Darwini* Morr. figured by De Koninck[3] from the marine Permo-Carboniferous of New South Wales, and the Russian Upper Carboniferous species *Sp. supracarbonicus* Tschern.[4] bear a considerable resemblance to our shell in the weak rounded broad lateral folds and in general shape.

Athyris aff. *protea*, Abich.

Pl. 34, fig. 11.

There is one imperfect specimen of a pedicle-valve of a brachiopod which seems closely to resemble the shell from the Kuling Shales of the Himalayas which Diener[5] has figured as *Athyris* [*Spirigera*] *protea* Abich, var. *alata*. Our example seems to have been subcircular in shape; the subangular edges of the sinus are elevated into narrow low folds, and the floor of the sinus is somewhat angulated posteriorly, though rounded anteriorly; the lateral lobes are somewhat flattened or slightly concave, and numerous weak concentric growth lamellae cross the whole surface. *A. protea* and its varieties were first described from the Otoceras beds of Djulfa, Armenia.

Orthotichia ? sp.

Pl. 33, figs. 12, 12a.

There is a much weathered valve of a large brachiopod (K 21·424) having the surface of the shell mostly destroyed, but showing internally a pair of rather long dental (?) plates which at first converge

[1] Hall and Clarke, *op. cit.*, pl. 36. figs. 17-22.

[2] Muir Wood, *Quart. Journ. Geol. Soc.*, LXXXI, 1926, pt. 2, p. 242, pl. XVI, figs. 1a-c, 2.

[3] De Koninck, *op. cit.* (*transl.*) 1898, p. 179, pl. X, figs. 11, 11a.

[4] Tschernyschew, *Mem. Com. Geol. Russ.* XVI, 1902, p. 553, t. XV, figs. 2, 3.

[5] Diener, Himal. Foss., Vol. I, pt. 5, 1903, (*Pal. Indica,* Ser. XV), p. 185, pl. IX, figs. 5a-d.

for a short distance and then diverge for the greater part of their length at an angle of about 30°. The shell was apparently subquadrate, moderately convex, most so posteriorly, with a weak very broad median sinus or depression anteriorly; the hinge-line is straight, and the beak is broad, obtuse, rounded, and slightly incurved; the cardinal angles which are imperfectly preserved were apparently rounded or obtuse. The pair of supposed dental-plates reach about one fifth the length of the shell. The surface shows traces of having possessed radial filiform striae, with concentric rugae or lamellæ on the flanks.

It was at first thought that this specimen was attributable to some species of *Orthothetes* such as *O. guadalupensis* Shum.[1] and *O. Kraffti* Diener,[2] but it seems more likely to belong to some species of *Orthotichia*, *Schizophoria* or *Enteletoides*, especially resembling *E. rossicus* Stuck.[3] from the Upper Carboniferous of Samara. Its generic reference is, however, a matter of doubt.

Indeterminable brachiopod (genus uncertain).

Pl. 35, fig. 10.

There is a small fragmentary brachiopod from Horizon. A. (K 23·261) represented by only one very imperfect specimen, 5-6 mm. long, which is different from any of those above described. It was apparently of a subquadrate or subcircular shape with a flattened surface bearing a weak median depression and about 16-18 strong straight radiating rounded ribs with scabrous ? elevations; the beak is small and rounded. In some respects it resembles *Strophalosia costata* Waag.[4] from the Lower Productus Limestone of the Salt Range, and *Aulosteges percostatus* Diener [5] of the Fenestella Series of Kashmir, but it may be merely a crushed pedicle-valve of some rhynchonelloid referable to *Liorhynchus*, *Camarotœchia* or *Camarophoria*.

[1] Girty, *Prof. Paper* 58, *U. S. Geol. Surv.*, 1908, p. 199, pl. X, figs. 1-5.

[2] Diener, Himal. Foss., Vol. I, pt. 5, 1903 (*Pal. Indica*, Ser. XV), p. 78, pl. III, figs. 6, 7.

[3] Stuckenberg, *Mem. Com. Geol. Russ.*, N. S., Livr. 23, 1905, pp. 60, 129, t. VI, fig. 8.

[4] Waagen, Salt Range Foss., I (*Pal. Indica*), p. 655, pl. LXIII, figs. 7, 8, pl. LXIV, figs. 1a-g.

[5] Diener, *Pal. Indica*. N. S., Vol. V, Mem. 2, 1915. p. 31, pl. III, figs. 4-7.

Janeia aff. *biarmica* (De Verneuil).

Pl. 36, fig. 14.

There is one small lamellibranch in the collection represented only by one right valve, and a fragment of another, both from Horizon D (K 23·264). The better specimen is suboblong in shape, abruptly truncated behind, but broadly rounded in front; the upper and lower edges are nearly straight and parallel; the beak is small broad low obtuse and situated far forward (but the anterior end of the valve is not well exposed); the valve is very slightly convex and has a broad very shallow median transverse depression crossing it obliquely; a weak low straight umbonal ridge runs back to the posterior lower angle, and above it the valve is somewhat flattened with traces of a narrow radial ridge on it; the whole surface of the valve is marked by concentric growth-lines and ridges of rather unequal strength which meet the hinge line nearly at right angles.

Dimensions.

Length	c.	5 mm.
Height	c.	3 mm.

Affinities.—From the general shape and characters of this shell it seems probable that it should be referred to some species of *Janeia* or *Solemya* rather than to *Allorisma*, *Sphenotus* or *Sanguinolites*, though it is shorter and broader than usual in that genus It somewhat resembles the Himalayan shell referred by Diener [1] to *Janeia biarmica* (De Vern.). *Sph. vulgaris* Girty,[2] also may perhaps be allied.

Pleurotomaria umariensis sp. nov.

Pl. 31, figs. 12, ? 13.
Pl. 35, figs. 11-13.

Shell small, turreted to sub-turbinate, conical, composed of 5-7 rounded or slightly subangular whorls increasing rather rapidly in size, bearing a broad submedian slit-band on the periphery; apical angle 45° or rather less. Whorls rather flattened above and rounded below;

[1] Diener, Himal. Foss. Vol. I, pt. 5, 1903, (*Pal. Indica*), p. 173, pl. VIII, figs. 7a, b, 8 ?

[2] Girty, *Bull.* 593, *U. S. Geol. Surv.*, 1915, p. 78, pl. VIII, figs. 5-7.

surface crossed by rather strong regular transverse fine lines meeting the slit-band on the lower surface at about 60° or more and on the apical surface at about 45°, but abutting against the suture line at right angles. Slit-band conspicuous, submedian, situated slightly below the middle of the whorls, rather deeply sunk between strong raised prominent edges and having its gently concave surface crossed by regular closely placed slightly curved lunulae. Body-whorl rounded below, large, being one third (or more) the height of the spire; base convex, deep, generally with a weak revolving keel a short distance below the slit-band. Mouth subcircular; columellar lip nearly straight, slightly thickened and flattened, sharply exsert. Umbilicus absent.

Dimensions (average).

Height	8 mm.
Diameter of basal whorl.	5 mm.

Remarks.—All the first examples (K 21·425) from the shell-band and the associated soft greenish shales were crushed and imperfect, except one small turbinate specimen (Pl. 34, fig. 13) which had an unusually low spire and wide apical angle and is doubtfully referable to this species. But Mr. Gee has since collected a large number of specimens from the lowest band D (K 23·461) and from K 22·972, 973, of the railway cutting, in which the species is extraordinarily abundant, and the specimens are often well preserved.

With regard to the characters of the species we may observe that the apical angle varies somewhat, some shells being broader and having a lower spire than others, but otherwise agreeing in every detail. The ornamentation is constant, except as regards the one revolving lira on the body-whorl, which may be absent and is always weak.

Diener [1] has described but not figured an unnamed species of *Pleurotomaria* from the Carboniferous beds of Lipak which seems to agree closely with the Umaria form. The figures and description of *Pleurotomaria delawarensis* Girty [2] from the Guadelupian fauna of the United States may be compared with our species, and there seems to be also a considerable resemblance to *Pl. kirillowensis*

[1] Diener, *Pal. Indica*, N. S., Vol. V, Mem. 2, 1915, p. 119.
[2] Girty, *Prof. Paper* 58, *U. S. Geol. Surv.*, 1908 p. 475, pl. XXIII, figs. 28-30.

Licharew [1] from the Permian of Russia. But perhaps *Pl. arkansana* Girty [2] from the Batesville Sandstone is more closely allied.

The precise subgeneric reference of our species is uncertain, but it may belong to *Ptychomphalina.*

Jonesina ? sp.

Pl. 31, fig. 14.

The entomostracean genus *Jonesina* is probably represented by a small suboval gently convex body rather wider at one end than the other, and of a slightly bean-shaped outline owing to a weak concavity near the middle of the upper margin which is rather shorter than the gently arched lower margin. The surface bears a small oval very faintly elevated subcentral swelling situated behind the middle and surrounded by a fine impressed line. In front of and in contact with this swelling and likewise very faintly circumscribed is a smaller less distinct subcircular eminence scarcely raised above the general surface.

Cytherella ? sp.

Pl. 31, fig. 16.

The carapace of another small ostracod is seen in a marginal view of the two conjoint valves showing a simple junction. The shell is ovate in shape and the valves seem to be equally convex and smooth. Probably this is referable to the genus *Cytherella*, and it seems to resemble in the inflation of the valves the species '*Cythere*' *inflata* McCoy.[3]

Palaeocypris ? sp.

Pl. 31, fig. 15.

A third type of ostracod is represented by one somewhat crushed valve. It is suboval in shape, rather blunter and broader at one end than the other, and its strongly convex surface is covered with rather widely separated small sharp granules of two or three sizes. Probably this is referable to the genus *Palaeocypris*.

[1] Licharew, *Mem. Com. Geol. Russ.*, N.S. Livr. 85, 1913, pp. 12, 87, t. V, figs. 3, 4.
[2] Girty, *Bull.* 593, *U. S. Geol. Surv.*, 1915, p. 113, pl. XI, fig. 8.
[3] McCoy, *Syn. Carb. Foss. Ireland*, 1844, p. 167, pl. XXIII, fig. 17.

Dermal tubercles of a fish.

Pl. 35, figs. 14-18a.

There are several specimens of a curious little pointed capuliform solid object (K 23·262) (K 23·264) (K 22·973) having a high rounded obliquely conical shape with a more or less sharply pointed straight or slightly curved apex directed backwards; the posterior slope below the apex is somewhat hollowed; the base of the tubercle is somewhat expanded and flattened, with a circular to suboval outline, but is thin and without any root. The cone appears to be solid, but the base of it is slightly excavated underneath. The surface of the cone is covered with small low closely-placed rounded granules. The largest specimen measures about 8 mm. in height and has the same diameter at the base. We may probably interpret this fossil as the dermal tubercle of some selachian and of the same nature as *Petrodus*. Sir A. Smith Woodward thinks it is a new genus.

AFFINITIES OF THE FAUNA AND CORRELATION OF THE BEDS.

The fauna of these Umaria beds has a striking individuality of its own, and it comprises only a few genera. The majority of the fossils are brachiopods, belonging to the genera *Productus*, *Spirifer* and *Reticularia*, the first named genus largely predominating. The species are found to be in all cases new when the material is sufficiently well preserved for their specific identification, and their affinities are not particularly close with any previously described forms, though their nearest relations are partly found amongst Himalayan and Russian species of Permo-Carboniferous and Permian age and partly amongst Carboniferous species. Thus *Productus umariensis* and its variety *spinifera* recall forms referred to *Pr. cora* and *Pr. cancriniformis*, while *Pr. rewahensis* seems allied to *Pr. Tschernyschewi* of the Russian Permian. *Spirifer narsarhensis* on the other hand is more like *Sp. grandicostatus*, *Sp. Middlemissi* and *Sp. Leidyi*, all occurring in the Carboniferous of other regions, while *Reticularia barakarensis* seems to have its nearest relative in *R. setigera* of the Lower Carboniferous of America. But the species of *Athyris* and the lamellibranch referred to *Janeia* are more allied to Permian species. The other fossils are hardly well enough known for any stratigraphical conclusions to be drawn from them.

The distribution of the species on the several horizons recognised by Mr. Gee does not suggest any important difference in the age of these bands, and most of the species seem common to them all.

For the association of marine fossiliferous beds with typical Gondwana plant-bearing series we have to go to Kashmir and Australia. In the case of Kashmir the Zewan (Permo-Carboniferous) Beds which contain a Productus Limestone fauna rest on the Gangamopteris Beds of the Lower Gondwana which in their turn repose on the Panjal Volcanics and Agglomeratic Slate of possible Talchir age. Below these volcanic beds are marine Carboniferous beds, the uppermost of which is known as the Fenestella series and is doubtfully referred to the Middle Carboniferous by Middlemiss.[1] The Syringothyris Limestone series which lies below is separated from the Fenestella series by some passage beds, and is definitely ascribed to the Carboniferous. But neither the fauna of the Fenestella nor of the Syringothyris beds, and even less that of the Zewan beds, shows any close general resemblance to that under consideration, though certain of the species are allied. In the Umaria locality the marine beds rest with a slight unconformity on the Talchir beds and pass up without a break into the Barakar stage of sandstones and coals which is at the base of the Damuda series. Wadia [2] places the Barakar stage in the Middle Permian, but Cotter [3] refers it to the Lower Permian. We might therefore expect *a priori* that the marine band at its base would perhaps correspond with the Karharbari which Wadia terms Permo-Carboniferous. Cotter correlates the beds of the Australian marine series which have plant-bearing deposits of Lower Gondwana type between and above them with the Karharbari series. It may be suspected that this marine bed at Umaria is of rather different date, but it cannot be considered to correspond with the Lipak or Po series of Spiti,[4] or the Fenestella series of Kashmir of which the faunas have been described by Diener.[5]

The importance of the discovery of a marine fossiliferous deposit below part of the Lower Gondwanas of Central India is obvious

[1] Middlemiss, *Rec. Geol. Surv. Ind.* Vol. XL, pt. 3, 1910, pp. 210, 222-232.

[2] Wadia, "Geology of India," 2nd edit., London, 1926, p. 116.

[3] Cotter, *Rec. Geol. Surv. Ind.*, XLVIII, 1917, pp. 23-33.

[4] Hayden, Geology of Spiti, *Mem. Geol. Surv. Ind.*, Vol. XXXVI, pt. 1, 1904, pp. 37-50; Wadia, *op. cit.*, pp. 99, 100.

[5] Diener, Himal. Foss., Vol. I, pt. 2, 1899, *Pal. Indica*, Ser. XV; *ibid.*, vol. I. pt. 5, 1903; *ibid.*, N. S., Vol. V, Mem. 2, 1915.

from a palæogeographical point of view. For it has been generally believed that the Peninsula was a land-area from at any rate the close of the Purana (Pre-Cambrian) era until late in Aryan (Palæo-Mesozoic) times and that it was never invaded, much less wholly submerged, by the sea till the Jurassic or Cretaceous period and even then it was only along the margins that marine incursions took place. In the light of the marine fossils at Umaria we can no longer maintain this opinion in its entirety, though to what extent the sea penetrated into the land cannot at present be determined. A partial submergence is, however, proved to have occurred, and the transgression which only lasted a short time was probably either from the north through Rajputana or from the west coast.

The evidence of the fossils inclines us to conclude that this marine invasion took place in Permo-Carboniferous times, as there is a noticeable admixture of types possessing affinities with both Carboniferous and Permian species. A study of the Carboniferous Permo-Carboniferous and Permian marine faunas in the Calcutta Museum confirms the author's conclusion that this Umaria fauna is distinct and unique.

EXPLANATION OF PLATES.

PLATE 31.

FIG. 1.—*Productus umariensis* sp. nov. Pedicle-valve of nearly complete specimen. × 1½. (K 21·426).

FIG. 1a.—*Productus umariensis* sp. nov. Brachial valve of same specimen. × 1½.

FIG. 1b.— Ditto. Cardinal view of same specimen. × 1½.

FIG. 2.— Ditto. Posterior part of pedicle-valve of another nearly complete specimen. × 1½. (K 21·424).

FIG. 2a.—*Productus umariensis* sp. nov. Cardinal view of same specimen showing cardinal thickening and spines. × 1½.

FIG. 2b.—*Productus umariensis* sp. nov. Brachial valve of same specimen, showing bifurcation of riblets. × 1½.

FIG. 3.—*Productus umariensis* sp. nov. Pedicle-valve of a shell devoid of spines on riblets, some of which are thickened. × 1½. (K 21·424).

FIG. 4.—*Productus umariensis* sp. nov. Cardinal view of another example without thickened riblets, showing cardinal spines. × 1½. (K 21·424).

FIG. 4a.—*Productus umariensis* sp. nov. Ventral view of same specimen. × 1½.

FIG. 5.— Ditto Median portion of surface of pedicle-valve, showing increase of riblets by division of thicker riblet below spine-base. × 6. (K 21·424.)

FIG. 6.—*Productus umariensis* sp. nov. Lateral portion of another shell, showing increase of riblets by intercalation and without spine-bases. × 2. (K 21·426.)

PLATE 32.

FIG. 1.—*Productus rewahensis* sp. nov. Pedicle-valve, partly buried in matrix, × 1½. (K 21·424.)

FIG. 1a.—*Productus rewahensis* sp. nov. Posterior view of same specimen. × 1½.

FIG. 2.—*Productus rewahensis* var. *coroides*. Pedicle-valve of complete shell. Nat. size. (K 21·424).

FIG. 2a.—*Productus rewahensis* var. *coroides*. Brachial valve of same specimen. Nat. size.

FIG. 3.—*Productus rewahensis* var. *coroides*. Another specimen, pedicle-valve. × 1½. (K 21·424.)

FIG. 3a.—*Productus rewahensis* var. *coroides*. Portion of surface of same specimen. × 4.

FIG. 4.—*Productus umariensis* sp. nov. Interior of pedicle-valve. × 1½. (K 21·426.)

FIG. 5.—*Productus umariensis* sp. nov. Posterior part of pedicle-valve of another specimen. × 1½. (K 21·424.)

FIG. 6.—*Productus umariensis* sp. nov. Brachial valve of complete shell. × 1½. (K 21·424.)

FIG. 7.—*Productus umariensis* sp. nov. Pedicle-valve of another specimen. × 1½. (K 21·424.)

FIG. 8.—*Productus umariensis* sp. nov. Brachial valve of a complete shell. × 1¼. (K 21·424.)

PLATE 33.

FIG. 1.—*Productus umariensis* var. *spinifera*. Pedicle-valve nearly complete, showing spines on surface. × 1½. (K 21·424.)

FIG. 1a.—*Productus umariensis* var. *spinifera*. Part of centre of surface of same shell. × 4.

FIG. 1b.—*Productus umariensis* var. *spinifera*. Part of surface of same shell near lateral margin. × 4.

FIG. 2.—*Productus umariensis* var. *spinifera*. Imperfect pedicle-valve with fewer spines. × 1½. (K 21·424.)

FIG. 3.—*Productus umariensis* var. *spinifera*. Posterior part of another pedicle-valve. × 1½. (K 21·424.)

FIG. 4.—*Productus umariensis* var. *spinifera*. Posterior part of pedicle-valve of another specimen, showing cardinal spines. × 1½. (K 21·424.)

FIG. 5.—*Productus umariensis* var. *spinifera*. Posterior part of pedicle-valve of another specimen, showing cardinal spines. × 2. (K 21·424.)

FIG. 5a.—*Productus umariensis* var. *spinifera*. Cardinal view of same specimen. × 2.

FIG. 6.—*Productus umariensis* var. *spinifera*. Fragment of interior of pedicle-valve, showing vascular markings outside diductor scars. × 1½. (K 21·424.)

FIG. 7.—*Spirifer narsarhensis* sp. nov. Complete specimen, dorsal view. × 2. (K 21·425.)

FIG. 7a.—*Spirifer narsarhensis* sp. nov. Ventral view of same specimen. × 2.

FIG. 7b.— Ditto. Anterior marginal view of same specimen. × 2.

FIG. 8.—*Spirifer narsarhensis* var. Imperfect pedicle-valve. × 2. (K 21·424.)
FIG. 9.— Ditto. var. Imperfect brachial valve. × 2. (K 21·425.)
FIG. 10.— Ditto. var. Imperfect pedicle-valve. × 2. (K 21·425.)
FIG. 11.—*Spirifer narsarhensis* var. *pauciplicata*. Imperfect brachial valve. × 2. (K 21·424.)
FIG. 12.—*Orthotichia* ? sp. Imperfect pedicle-valve. × $1\frac{1}{4}$. (K 21·424.)
FIG. 12a.—*Orthotichia* ? sp. Cardinal view of same specimen, showing dental plates. × $1\frac{1}{4}$.

PLATE 34.

FIG. 1.—*Reticularia barakarensis* sp. nov. Pedicle-valve with worn surface. × $1\frac{1}{2}$ (K 21·424.)
FIG. 1a.—*Reticularia barakarensis* sp. nov. Portion of surface of same specimen with spinules abraded. × 7.
FIG. 2.—*Reticularia barakarensis* sp. nov. Imperfect brachial valve. × $1\frac{1}{2}$. (K 21·425.)
FIG. 2a.—*Reticularia barakarensis* sp. nov. Portion of surface of same specimen showing well-preserved ornamentation. × 6.
FIG. 3.—*Reticularia barakarensis* sp. nov. Pedicle-valve of a young individual × 2. (K 21·425.)
FIG. 4.—*Reticularia barakarensis* sp. nov. Portion of shell with well-preserved fimbriated lamellæ. × 6. (K 21·424.)
FIGS. 5, 5a.—*Reticularia barakarensis* sp. nov. Impressions of different parts of surface of one shell, showing variation in appearance of ornamentation. × 6. (K 21·424.)
FIG. 6.—*Reticularia barakarensis* sp. nov. Portion of surface of another shell showing well-preserved fimbriated lamellæ. × 6. (K 21·425.)
FIG. 7.—*Reticularia barakarensis* sp. nov. ? Impression of part of surface of another shell with indistinct concentric arrangement of spinules. × 6. (K 21·425.)
FIG. 8.—*Reticularia barakarensis* sp. nov. Pedicle-valve, showing dental plates. × $1\frac{1}{2}$. (K 21·424.)
FIG. 8a.—*Reticularia barakarensis* sp. nov. Posterior view of same specimen. × $1\frac{1}{2}$.
FIG. 9.—*Reticularia barakarensis* sp. nov. Brachial valve (uncrushed). × 2 (K 21·425.)
FIG. 10.—*Reticularia barakarensis* sp. nov. ? Internal cast of young pedicle-valve. × 2. (K 21·424.)
FIG. 11.—*Athyris* aff. *protea* Abich. Imperfect pedicle-valve. × 2. (K 21·425.)
FIG. 12.—*Pleurotomaria umariensis* sp. nov. × $2\frac{1}{2}$. (K 23·264.)
FIG. 13.—*Pleurotomaria umariensis* sp. nov. Short turbinate variety. × 6. (K 21·425.)
FIG. 14.—*Jonesina* ? sp. × 8. (K 21·425.)
FIG. 15.—*Palæocypris* ? sp. × 8. (K 21·425.)
FIG. 16.—*Cytherella* ? sp. × 6. (K 21·425.)
FIG. 17.—*Rhombopora* sp. × 6. (K 21·425.)

PLATE 35.

FIG. 1.—*Productus rewahensis*, sp. nov. Pedicle-valve. × 1½. (K 23·263.)
FIG. 1a.— Ditto. Posterior view of same specimen. × 1½.
FIG. 2.— Ditto. Pedicle-valve. × 1½. (K 23·263.)
FIG. 3.— Ditto. Posterior view of another pedicle-valve. × 1½. (K 23·263.)
FIG. 4.—*Productus rewahensis*, sp. nov. Pedicle-valve. × 1½. (K 23·264.)
FIG. 5.— Ditto. Pedicle-valve. × 1½. (K 23·263.)
FIG. 6.— Ditto. Interior of brachial valve. × 1¼. (K 23·264.)
FIG. 7. *Productus rewahensis*, sp. nov. Internal cast of pedicle-valve. × 1¼. (K 23·264.)
FIG. 8.—*Productus rewahensis* var. *coroides*. Pedicle-valve. × 1½. (K 23·261.)
FIG. 8a. Ditto. Side view of same specimen. × 1½
FIG. 9.—*Productus umariensis* var. *spinifera*. Pedicle-valve. × 1½. (K 23·262.)
FIG. 10.- Indet. brachiopod (genus uncertain). × 6. (K 23·261.)
FIG. 11.—*Pleurotomaria umariensis* sp. nov. × 3. (K 23·264.)
FIG. 12.— Ditto *ditto.* × 3. (K 23·264.)
FIG. 13.— Ditto *ditto.* × 2½. (K 23·264.)
FIG. 14.— Dermal tubercle of fish. Side view. × 2. (K 23·262.)
FIG. 14a.— Ditto. Portion of surface. × 6.
FIG. 15.— Ditto. Side view of another specimen. × 2. (K 23·264.)
FIG. 16.— Dermal tubercle of fish. Side view of another specimen. × 2. (K 23·262.)
FIG. 16a.— Dermal tubercle of fish. Top view of same specimen. × 2.
FIG. 16b.— Ditto. Front view of same specimen. × 2.
FIG. 17.— Ditto. Side view of another specimen. × 2. (K 23·262.)
FIG. 17a.—Dermal tubercle of fish. Front view of same specimen. × 2.
FIG. 18.— Ditto. Side view of another specimen. × 2. (K 23·262.)
FIG. 18a.—Dermal tubercle of fish. Front view of same specimen. × 2.

PLATE 36.

FIG. 1.—*Spirifer narsarhensis*, sp. nov. Pedicle-valve. × 1½. (K 23·262.)
FIG. 1a.— Ditto. Interior of same specimen. × 1½.
FIG. 2.— Ditto Pedicle-valve. × 1½. (K 23·262.)
FIG. 3.— Ditto. Pedicle-valve. × 1½. (K 23·262.)
FIG. 4.— Ditto. Pedicle-valve. × 1½. (K 23·262.)
FIG. 5.— Ditto. var. Brachial valve. × 1½. (K 23·262.)
FIG. 6.— Ditto, var. *pauciplicata.* Brachial valve. × 2. (K 23·262.)
FIG. 7.— *Spirifer narsarhensis*, var. *pauciplicata.* Pedicle-valve. × 2. (K 23·262.
FIG. 8.—*Reticularia barakarensis*, sp. nov. Pedicle-valve. × 1½. (K 23·262.)

FIG. 8a.—*Reticularia baarkarensis*, sp. nov. Brachial valve of same specimen. × 1½.

FIG. 9.—*Reticularia barakarensis*, sp. nov. Another brachial valve. × 1½. (K 23·262.)

FIG. 10.—*Reticularia barakarensis*, sp. nov. Brachial valve with shell preserved. × 1½. (K 23·262.)

FIG. 11.—*Reticularia barakarensis*, sp. nov. Pedicle-valve of young individual × 1½. (K 23·262.)

FIG. 12.—*Reticularia barakarensis* var. *subplicata*. Pedicle-valve. × ¾. (K 23·262.)

FIG. 13.—*Reticularia barakarensis* var. *subplicata*. Pedicle-valve. × 1¾. (K 23·262.)

FIG. 14.—*Janeia* aff. *biarmica* (De Vern.). Right valve. × 5. (K 23·264.)

FIG. 15.—Crinoid stem. × 2½. (K 23·262.)

FIG. 15a.— Ditto. articulating face of same specimen. × 2½.

THE GEOLOGY OF THE UMARIA COALFIELD, REWAH STATE, CENTRAL INDIA. BY E. R. GEE, B.A. (CANTAB.), *Assistant Superintendent, Geological Survey of India.* (With Plates 37 to 39.)

INTRODUCTION.

THE completeness, so far as the coal-deposits were concerned, of the geological survey of the Umaria coalfield carried out by Mr. T. W. H. Hughes of the Geological Survey of India, in the early eighties,[1] rendered dormant the specialised attention of Indian geologists to this area, until in the year 1921, considerable scientific interest was aroused by the discovery by Mr. K. P. Sinor, Rewah State Geologist, of a marine fossil bed in these Lower Gondwana sediments.[2]

Following a visit by Dr. C. S. Fox to this coalfield, I was deputed during the month of June 1926 to make a geological resurvey of the area, to examine in detail the Lower Gondwana strata in which these marine fossils occur, and to add to the collection if possible. The additional forms which were collected have been described by Dr. Cowper Reed in an adjoining paper.

The attached geological map (Plate 39), represents the results of this resurvey. Comparing it with the one in Mr. Hughes' memoir, the main difference is seen to be in the distribution of the Supra-Barakar rocks in the western part of the area. Considering, however, the importance of the recent palæontological discovery, and bearing in mind the similarities and differences which the Gondwanas of this area exhibit when compared with their equivalents in Bengal and elsewhere, it seems worth while to record the Gondwana succession of this coalfield in greater detail than has previously been done.

Physical geography of the area.

The Umaria coalfield itself forms a relatively level cultivated tract, about 1,460 feet above sea-level. It opens out to the east and north-east, but is bounded on the west and south by thickly forested ridges which attain an altitude of about 1,800 feet. The

[1] *Mem. Geol. Surv. Ind.*, Vol. XXI, 1925.

[2] *Rec., Geol. Surv. Ind.*, Vol. LIV, 1922, p. 14, *Bull. No. 2, Geological Dept., Rewah State,* ' Rewah State Coalfields (1923), pp. 1-22.

Katni-Bilaspur branch of the Bengal-Nagpur railway traverses the area in a general north-west to south-east direction, Umaria itself being 36 miles distant from Katni station. The strata of the southern part of the coalfield are to a great extent hidden by alluvium, but to the north-west of Umaria the more porous sandy Gondwanas crop out. The main line of drainage—the Umrar river—meanders across the coalfield in a general northerly direction, while a number of small tributaries traverse it in a north-easterly direction from the uplands to the west and south.

General geology and geological structure.

The geological formations met with in the Umaria coalfield include :—

Alluvium.

Trap.

Gondwanas. { Supra-Barakars. / Barakars. / Talchirs.

Metamorphics.

There is, as is to be expected, a very close relationship between the main physical and the geological features of the area. The wooded uplands to the south of the coalfield represent the ancient metamorphic land-surface against which the Gondwanas were deposited. To the north-west the crystalline rocks again constitute the boundary of the field, but here the junction is a faulted one. The general dip of the strata being in a northerly direction, newer beds are met with as we traverse the coalfield from south to north. This simple structure has, however, been complicated as a result of folding which has thrown the beds into a sharp syncline close to the Narsarha fault and a more gentle anticline further south-east towards Umaria. Evidence will be given later that this faulting along the north-western edge of the field, accompanied by an inclination of the strata near the fault, commenced previous to the deposition of the Barakar strata, and continued more actively during the period of formation of the Supra-Barakars; with the result that these Supra-Barakar rocks, in the vicinity of the fault, overlap on to the lower Barakar horizons and finally on to the Talchirs also. This overlap increases in the upper Supra-Barakar rocks, so that, as the vertical displacements continued, these strata also were in places brought into faulted juxtaposition with the metamorphics.

DETAILS OF THE VARIOUS FORMATIONS.

The following is a description of these various formations in detail.

I.—THE METAMORPHICS.

The Metamorphics include a variety of types considerably foliated and penetrated by numerous quartz and pegmatite veins. Specimens, typical of the area, were commented on by Dr. Heron as being closely comparable to the gneisses of the Rajputana area. To the south of the coalfield these rocks include pink and grey felspathic gneisses and hornblendic types, associated around Karmati with bands rich in magnetite iron-ore. The foliation dips usually at a steep angle to the south and south-south-west. The continuous outcrop of these metamorphics passes along the edge of the jungle to the south of Koilari, but, in the village itself, an outcrop of white quartzite again occurs. It seems probable, therefore, that the gneisses would be met with at no great depth immediately below the alluvium in the intervening area to the south of Koilari village.

Immediately north-west of the Narsarha fault finely foliated micaceous schists and white quartzites predominate. Coarser textured felspathic gneisses come in further west, and include large pegmatite veins, in some cases rich in soda felspar, in others, rich in mica. The quartzites met with close to the fault, especially to the north-east of the railway, are usually much brecciated. The gneisses and schists dip almost vertically and strike in a north-east to south-west direction parallel to this faulted boundary of the coalfield.

II.—THE GONDWANAS.

Talchir sections along the south side of the Coalfield.

The Talchirs.—The most complete section of the Talchir rocks is seen in the north-easterly-flowing tributary of the Umrar river to the south of Bikatganj. The geological succession is as follows :—

(Yellow-brown fine textured soft sandstones.—Basal Barakars.)

Red and green stratified clays.

Conglomerate, of fairly well rounded boulders of gneiss and quartzite set in a dull-green clayey matrix.

Yellow and light green bedded clays and fine argillaceous sandstones including bands with a few rounded pebbles. The clays include at intervals narrow bands of calcareous light green mudstone up to 6 inches in thickness. The dip is to the north-north-east at about 12°.

Soft greenish felspathic grit with quartzite pebbles.
Green clays including boulders of gneiss and quartzite.

(Pink felspathic gneisses, dipping south at 60°).

In the main Umrar river all exposures of the Talchirs are hidden by alluvium until we approach the gneissic boundary to the south of Mahroi. At this point, within a short distance of the Metamorphics, yellow green Talchir conglomerates are seen to crop out in the river-bank.

In the tributary east of Chandwar the junction of the Talchirs with the gneisses is again fairly well defined. A greenish conglomerate crops out, separated from the Metamorphics by a narrow band of alluvium. With this boulder-bed yellow green argillaceous sandstones and clays are associated, but a short distance further north an east-to-west running fault appears to bring in more arenaceous types, together with a yellow-grey fine calcareous sandstone weathering in an irregular tufaceous manner. To the north and west of Chandwar village, however, the Gondwana strata are again obscured by dull green clayey alluvium so that the geological boundaries are very indefinite in this vicinity. No Talchir outcrops are seen until we reach the Narsarba *nala* to the east and south of Paunian. In the acute southern loop of this main stream, half a mile east-south-east of Paunian, yellow-green argillaceous sandstones and clays, including boulders of gneiss and quartzite, dip at about 20° to the north-north-east. These exposures are separated by a short stretch of sandy alluvium from the Supra-Barakar rocks observed in the same stream-course, a short distance to the north. The section is again obscured in places by alluvium, but, further west, red and green conglomeratic clays, considerably indurated, crop out against the main north-west fault in the tributary west of Paunian. The typical splintery clays of the Talchirs are not seen, though the strata noted closely resemble some of the beds met with in the section south of Bikatganj.

The Talchirs of the Narsarha railway cutting.

The next Talchir section to be described is that of the railway cutting of the Bengal-Nagpur line (*See* Plate No. 37). Here the Talchirs crop out over a distance measured horizontally, of about 52 yards. They are inclined at a fairly steep angle to the south-east, but close to the metamorphics the splintery nature of the clays renders the dip unobservable. Dull red and

green splintery clays, including occasional large boulders of gneiss and quartzite, probably of local origin, comprise the greater part of the Talchir group in this section. In the upper part of the section, about 45 yards from the metamorphics, these splintery clays give place to yellow sandy varieties showing definite stratification, and dipping south-east at 36°—38°. Resting on these beds with slight unconformity, are the gritty red clays with argillaceous limestone bands, which include the marine fossils, brachiopods and small gastropods. These latter beds comprise the base of the Barakars.

The rocks adjoining the north-western boundary-fault.

The Talchir-Metamorphic faulted boundary is almost vertical. Grey micaceous foliated schists are brought into contact with the Talchir clays and, though the boundary in this section shows no evidence of marked shattering, this is perhaps explicable by the fact that the beds on both sides of the fault are of a comparatively soft elastic nature; furthermore, the stratification of the Talchirs near the fault, owing to the fragmentary nature of the clays, is not observable. At other points along the line of the supposed fault, however, conclusive evidence, in the nature of intense crushing and silicification, can be seen. Continuing north-east, in the neighbourhood of this Metamorphic boundary, no exposures of the adjacent Gondwanas are observed until the first tributary crossing the fault in an east-south-easterly direction is reached; here, indurated Talchir conglomerates crop out. A better section is, however, seen further east in the tributary just west of the "C" of Chhatan. Here the rocks at the immediate boundary comprise much brecciated and silicified Talchir conglomerate, showing marked evidence of a faulted contact. These beds are well-exposed, dipping steeply to the south-east, adjoining the Metamorphics. A few yards downstream, the unaltered green Talchir clays, including boulders of gneiss and quartzite, crop out. Separated from these rock-exposures by a short stretch of alluvium, yellow-green clays and soft sandstones occur. These may be either of Talchir or of Lower Barakar type. In the tributary about half a mile south-east of the railway cutting silicified Talchir sandstones and conglomerates are exposed.

North of the village of Chhatan, alluvium again hides the older strata, but when we approach the Umrar river the Supra-Barakar beds, dipping steeply to the south-east, are brought against the crystallines. Further north, where the fault crosses the river,

definite Talchir conglomerates, silicified and considerably brecciated strongly indicative of a faulted junction, crop out against the gneisses. In the acute bend to the west of Banrori, although the actual junction is hidden by alluvium, yellow and green pebbly clays and sandstones come in about 30 feet to the east of the gneisses, dipping south-east at 10°. These sediments give place to grey massive sandstones in the tributary to the east.

The coal-bearing Barakar rocks.

The Barakars.—From an economic standpoint the most important area of Barakar rocks is to the north of the railway in the vicinity of Umaria. In this locality several coal-seams have been located in the middle and upper parts of the series; these are being worked by the Rewah State collieries. South of the railway, however, the lower Barakar strata crop out above the Talchir sediments of the tributary south of Bikatganj.

The lower Barakars near Bikatganj.

These rocks include a basal yellow-brown, fine textured, soft sandstone, resting, apparently conformably, on the uppermost Talchir shales and conglomerates. As we approach the junction of the two main tributaries massive grey sandstones, more typically Barakar in character, come in, with coarse grits and a thin pebble-bed in the upper part. Above these strata massive grey felspathic sandstones again crop out. Close to the junction with the Umrar river these sandstones include a 14-15 inch coal seam, with shales and fireclays above and below. The middle and upper beds of the Barakar series have been carefully described by Hughes (*op. cit*). They include mainly the typical massive grey sandstones with intercalated coal-seams and fireclays, but reddish and yellow sandstones are also included in this series. These beds crop out in the Umrar river to the north of Umaria village, but to the west of Lalpur and for some distance to the north no exposures are seen on account of alluvium. The upper strata of the series are well observed in the tributary flowing north to Oatsganj.

The Barakars of the Narsarha railway cutting.

From a purely geological point of view, by far the most interesting outcrop of the Barakars is seen in the Narsarha cutting of the railway, two miles north-east of Umaria railway station. It is here that the marine fossil horizon is exposed (*See* Plate 38). The section of these Barakar sediments is a comparatively narrow one, attaining only about 320 feet measured

along the railway line, for the strata are rapidly overlapped by the Supra-Barakar pebble-beds in the southern part of the cutting. The lowest beds, resting upon the uppermost yellow-brown sandy clays of the Talchirs, comprise argillaceous rocks of somewhat similar lithology to the Talchirs below; these strata, however, pass up quite gradually into sandy clays and sandstones of Barakar facies, whilst a slight, but definite unconformity appears to separate them from the Talchir rocks below.

Details of the marine fossil horizon.

There appears to be considerable lateral variation in detail in these marine fossil beds. The best section is observed in the western slope of the cutting, and it is this section which will be described. The lateral variation is exemplified in the two detailed sections tabulated below:

Measured sections of the marine fossil beds as exposed in the western slope of the Narsarha Cutting.

(About 15 feet above the railway line.)	(About 27 feet above the railway line.)
Soft yellow-grey sandstones with bands of yellow-green clays.	Soft yellow-grey sandstones with bands of yellow-green clays.
(A) 8 inches. Soft yellow sandstones, with small rounded pebbles and including a number of large brachiopods (*Productus*).	(A) 8 inches. Sandy yellow-brown layer with small quartzite pebbles and large brachiopods (*Productus*).
12 inches. Dull reddish and grey-green clays.	12 inches. Dull red and drab grey clays.
(B) 1½ inches. Yellow-brown soft sandy band with numerous large and small brachiopods (*Productus* and *Spirifer*).	(B) 1 inch. Thin sandy band with few brachiopods.
8 inches. Dull red and greenish clays.	9 inches. Red and green clays.
(C) 4-5 inches. Hard calcareous shell-bed including similar brachiopods.	(C) 2 inches. Hard calcareous brachiopod shell-band.
9-10 inches. Red and green gritty clays including brachiopods at the base.	2 inches. Dull red and grey-green clays.
4 inches. Red and grey gritty clays.	

Measured sections of the marine fossil beds as exposed in the western slope of the Narsarha Cutting—contd.

(About 15 feet above the railway line.)

5 inches. Hard grey calcareous gritty band with brachiopods at the base.

5 inches. Gritty clays.

1 inch. Calcareous grit band.

(D) 12 inches. Dull red and green gritty clays, including brachiopods and numerous small gastropods at the base.

$1\frac{1}{2}$ inches. Hard grey calcareous grit.

15 inches. Dull red and green clays with gneissic boulders included, and occasional brachiopods (*Productus*).

2-4 inches. Grey calcareous argillaceous band.

(About 27 feet above the railway line.)

$1\frac{1}{2}$ inches. Grey calcareous grit band.

2 inches. Gritty green clays.

$1\frac{1}{2}$ inches. Grey calcareous band.

$2\frac{1}{2}$ inches. Grey green gritty clays.

2 inches. Grey calcareous band.

2 feet. Dull grey-green clays with pebbles.

3 inches. Hard calcareous band.

(These lower strata continue to converge and die out up the slope.)

3 feet. Dull green clays with a hard calcareous band, and including gneissic pebbles; it thins out up the slope.

Yellow sandy Talchir clays.

A small dip-fault of a few inches throw intercepts these strata (*See* Plate 38).

Noting the general relationships of these Barakar sediments of the cutting, one sees that they include an uppermost brown earthy sandstone bed dipping S.15°E. at 30°, below which are soft yellow and grey argillaceous sandstones with bands of light green and grey clays inclined at 34°. A similar dip is noted in the uppermost fossil horizons which follow beneath. There was no evidence to suggest an unconformity between these lower Barakar sandstones and the marine fossil strata. The lithology indicates a gradual transition from the yellow argillaceous sandstones including the *Productus* horizon (A) in its lower part, to the dull green and reddish clays in which the lower fossil zones are included. The strata, including the three upper fossil horizons (A) to (C), appear to continue with similar thickness and dip up and into the western side of the cutting, and are probably represented in slightly varied form in the fossil horizons of the eastern slopes. Below the (C)

horizon, however, the beds show considerable lateral variation in thickness and a peculiar slight unconformity on the Talchir strata below them. They thin out when traced up the western bank and exhibit a definite overlap of the upper fossil horizons on to the lower ones, and possibly on to the yellow sandy Talchir beds below. (*See* Plate 38). In fact, these lower fossiliferous clays, with intervening harder, grey, calcareous, argillaceous bands, appear to occur in a definitely lenticular form, the lenticle closing near the edge as we go south-westwards, up and into the south-western slope of the cutting. Thinning out takes place of both the red and green gritty clays with fossils, and of the intercalated calcareous bands. It appears, therefore, that this lateral variation is neither the result of surface creep in the upper slopes, nor is it due to the squeezing out of the softer intercalated clays; the exposure described reaches not more than halfway up the side of the cutting and is cut well into the rock *in situ*. The section suggests a definite slight unconformity on the Talchir beds, the latter forming a slightly concave shelving base of deposition, which was filled up by the boulder-bearing clays and lowest marine beds, after which a slight rise in the relative sea-level resulted in the overlapping of the upper zones across the lower ones. Following this, a period of conformable deposition occurred with a gradual change of conditions, resulting in the shallow-water deposits of the lower Barakar sandstone stage.

Suggested conditions of deposition.

The difference between the Talchir-Barakar deposits of the railway cutting and of those sections along the southern unfaulted boundary of the field is doubtless explained by the varying conditions of deposition in the two localities. It is suggested that downward movement along the south-east side of the north-western boundary fault of the coalfield commenced previous to the formation of these Lower Barakar strata, so that the Upper Talchir rocks of that area formed a gradually shelving or locally undulating marine bed very suitable for the existence and accumulation of such marine organisms. This relative displacement, at the same time, caused the Upper Talchir rocks to be locally exposed to the erosive action of marine currents and so provided material of similar lithological character for the formation of the Lower Barakar fossil beds. At a slightly later date the conditions of deposition of the typical Lower Barakar sandstones, unfavourable to marine life, spread westwards, and

resulted in the extermination of this local colony, and the establishment of Lower Barakar conditions throughout the coalfield. At a later date, further downward movement along this line of faulting resulted, doubtless, in the rapid overlap of the Supra-Barakar beds.

Efforts to locate the fossil horizons in the stream sections near the boundary fault on either side of the cutting met with no success. The exposures are disappointing and might well explain the apparent absence of these fossil-beds; for although the indurated Talchir rocks were often seen against the Metamorphics of the fault-boundary, and the overlapping Supra-Barakars a short distance to the south-east, the strata of the intervening tract were invariably hidden by alluvium, so that no continuous section was observable. In addition it should be remembered that from the evidence of the sections in the Narsarha cutting, the strata including these marine fossils are of lenticular form, varying considerably when traced laterally. This suggests that the organisms existed in local colonies, possibly separated by areas where, owing to local factors, conditions were unfavourable for their existence. If such were the case, considering the very few complete sections of the rocks of the Lower Barakar stage met with in this coalfield, it is not surprising that no other fossiliferous locality was discovered.

The Supra-Barakars.—The Supra-Barakar strata include a lower series of grey, yellow and orange, soft, felspathic sandstones, medium to coarse-textured, alternating with thick brightly-tinted clays, usually red, purple, or light green in colour, together with an upper series of similar soft sandstones, including beds of well-rounded quartzite pebbles set in a soft sandy matrix.

The lower group of sandstones and clays apparently overlap the uppermost Barakar beds to the north of Umaria. In the vicinity of Loharganj these Supra-Barakar strata are brought into faulted juxtaposition with the Metamorphics, and are well-exposed, acutely folded, and striking parallel to the fault. They are well seen in the stream flowing in an east-north-east direction towards Oatsganj, where they dip at a fairly steep angle to the north and north-northwest. In the distributaries flowing south-east from the Metamorphics the dip is seen to change rapidly to the south-south-east, again at a steep angle. In these stream sections the upper sandstones and pebble-beds appear to rest upon the soft yellow sandstones —probably Barakar—which are separated by a

The Supra-Barakars of the Narsarha railway cutting.

short stretch of alluvium from the Talchir conglomerates of the fault face. The intervening lower Supra-Barakar beds—the soft sandstones and variegated clays—are apparently overlapped towards the fault. These pebble-beds and sandstones, exposed in the north-western limb of the syncline, continue to crop out south-westwards in the stream sections to within about 700 yards of the Narsarha cutting. In this intervening portion, however, alluvium obscures the strata. In the south-eastern part of the railway cutting exactly similar soft felspathic gritty sandstones and conglomerates are exposed resting directly on the Lower Barakar yellow sandstones which occur above the marine fossil-bearing beds. These sandstones and quartzite pebble-beds are of the same yellow and reddish tinges and include a badly exposed band of red clay at their base; they dip in a southerly direction at an angle of from 15° to 20°. From their lithology and from their mode of occurrence when compared with the above-mentioned sections to the north-east, there seems little doubt that these pebble-beds of the railway-cutting belong to the Supra-Barakar conglomerate horizon. There appeared to be no evidence of a fault separating these strata from the soft Barakar sandstones which occur further north along the cutting. The section is best explained on the supposition that relative movement along the boundary-fault was still in progress, and being accompanied by an inclination of the older sediments in the vicinity of the fault, these upper pebble-beds naturally overlapped the lower strata to within a short distance of the Talchirs. On the contrary, on the southern side of the coalfield where the faulting is absent, such intensive overlapping of the various Gondwana stages has not taken place. Occasional outcrops of red clays, largely obscured by dark clayey alluvium, occur in the stream-course just west of the railway between the Narsarha cutting and Umaria station. With them are associated yellow-grey hard calcareous sandstones weathering in an irregular tufaceous manner. To the south-west the soft pebbly sandstones and red clays are seen in the Paunian *nala* to be brought against the Metamorphics of the boundary-fault, the dip of these Supra-Barakar strata increasing to a fairly steep angle as the fault is approached. These sediments are separated by only a short stretch of alluvium from the conglomerates and clays of the Talchirs to the south. Again, to the north-east of the railway-cutting, where the fault approaches the Umrar river, these Supra-Barakar strata are brought against the faulted crystallines, the

crushed rocks near the boundary being considerably indurated, silicified, and quartz-veined, whilst a short distance south-east of the fault the beds are thrown into a sharp fold.

The line of hills running north-east of Banreri village is composed largely of massive sandstones and pebble-beds of the Supra-Barakars, associated with red ochreous clays. These strata are, apparently, cut off to the north-west by the continuation of the boundary fault.

III.—TRAP.

No occurrence of trap-rock *in situ* is met with actually within the coalfield. To the south-east, however, a short distance east of Karimati, sills of basalt cap the isolated sandstone hillocks. These represent outliers of the extensive flows which cover the wooded uplands to the south.

Trap occurrences.

IV.—ALLUVIUM.

A short distance south of the railway in the vicinity of the Umrar river dark-brown and black alluvium, including numerous well-rounded boulders of trap-rock, forms a thick covering over the older strata, and extends southwards to Mahroi. Dark clayey alluvium is again met with over a large portion of the area south-west of the railway between the Narsarha cutting and Umaria station, and forms a very fertile soil for cultivation.

LIST OF PLATES.

ON THE COMPOSITION AND NOMENCLATURE OF CHLOROPHÆITE AND PALAGONITE, AND ON THE CHLOROPHÆITE SERIES. BY L. LEIGH FERMOR, O.B.E., D.SC., A.R.S.M., F.A.S.B., F.G.S., *Officiating Director, Geological Survey of India.*

CONTENTS.

I.—INTRODUCTION.

In a recent paper Dr. M. A. Peacock [1] has given an account of the palagonitic tuffs of Iceland. In this paper he describes the macroscopic and microscopic appearances of both the sideromelan and palagonite of Von Waltershausen. In addition, analyses are given. The previously held view that the palagonite of Iceland is a hydrated form of sideromelan is confirmed, and the similarity of palagonite and chlorophæite, pointed out by the present writer,[2] is noted.

Dr. Peacock observes, however, that the actual process by which palagonite has been formed from the basalt glass, for which he uses the name sideromelan of Von Waltershausen, is different from the late magmatic changes to which various authors, myself included, have attributed the formation both of chlorophæite and of the related constituent of basaltic lava flows to which the term palagonite has been applied not only in India but elsewhere. Dr. Peacock recommends, therefore, that the use of the term palagonite to denote certain late magmatic hydrous materials in basalts and dolerites be discontinued; and he has had the courtesy to write to me to suggest that I should propose for this purpose some term instead of palagonite.

[1] *Trans. Roy. Soc. Edin.*, LV, pp. 51-76, (1926).
[2] *Rec. Geol. Surv. Ind.*, LVIII, pp. 140-141, (1925).

Before considering what term should be selected, it seems desirable to see whether we agree with Dr. Peacock in his suggestion that another term is necessary. The reasons for Dr. Peacock's suggestion may be summarised as follows :—(1) palagonite is the hydrogel of sideromelan and has been formed in some cases at low temperatures by submersion in water and in others as the result of hot-spring action, (2) chlorophæite and the palagonite, so-called, of the Indian basalts and similar rocks elsewhere, have been formed, in the view of the authors describing these rocks, as the result of late magmatic changes, and these changes have, in some cases, affected not only the interstitial glass of the original basalts, but also the augite, iron-ore, and even occasionally the labradorite felspar, the change being evidently in part one of replacement. In fact, Dr. Peacock wishes to restrict the term palagonite to 'the hydrogel of sideromelan which occurs only in fragmental basaltic ejecta'.

Now, it appears to be a sound principle that rocks or minerals should be named according to their composition and structure, and that in this process the views of an author concerning the origin of the rock or mineral should be suppressed as far as possible, so that subsequent possible changes of view should not necessitate changes of name. Two rocks or two minerals of diverse origin, but of similar composition and structure, should receive the same name. Taking the Archæan formations of India, for instance, a rock composed of interlocking quartz grains is correctly described as a quartzite whether it has been formed by the metamorphism of a pure quartz sandstone or by crushing, that is granulitisation, of vein quartz. Similarly, a banded metamorphic rock composed of felspar, quartz, and biotite is described as a biotite-gneiss whether it has resulted from the metamorphism of an original granite or from the metamorphism of a shale. The geologist may express his views of the origin of the quartzite or of the gneiss by suitable descriptive adjectives; but, primarily, the name should be selected on the basis of what the rock is now, and not on the basis of the geologist's view, which may be wrong, of the origin of that rock.

Coming now to the term under discussion we observe that Dr. Peacock bases his suggestion that different names are required for these two classes of products, (*a*) upon the suggested difference between the materials from which they have been produced and (*b*) upon the differences in the processes by which these materials

have been formed in the view of the geologists who have described them. It appears to me that, in accordance with the principles expressed in the preceding paragraph, even if these two differences can be sustained, different names will be applicable to the respective products only if they are substantially different chemically and physically. On the other hand, if they are similar chemically and physically, it does not matter whether the original materials from which they were formed, or the processes by which they were formed, were similar or different, one name should be applicable to both. However, it will be interesting first to examine briefly the two supposed differences referred to above.

Sideromelan is a name given by Von Waltershausen to the unaltered glassy material constituting the tuffs from which the palagonite of Iceland has been formed. A reference to page 57 of Dr. Peacock's paper shows, however, that the composition of this sideromelan is but slightly different from that of a normal basalt. Comparing this analysis with Washington's series of 11 analyses of Iceland basalts [1] it is seen at once that this analysis is very similar to that of other Iceland basalts (it is slightly on the low side in silica and potash). There seems, in fact, to be no special reason why the term sideromelan should be preserved at all The general name for basalt glass is *tachylyte* and although in practice the majority of tachylytes may be, as Dr. Peacock points out, characteristically opaque, yet this cannot be regarded as universally applicable. In India many of the basalt dykes of Deccan Trap age have glassy margins; when this glassy substance is examined in thin sections under the microscope, it is found to be glassy clear except for scattered phenocrysts of fresh felspar and fresh olivine, as is described by Dr. Peacock in the case of his sideromelan. If these glasses should be termed sideromelan because of their transparency, then the term is no longer restricted to tuffs. On the other hand, if the term sideromelan be not used because the rock is not a tuff, then there is no alternative to the use of tachylyte, and at once we have an example of transparent unclouded tachylyte. It seems to me better to recognise that tachylyte is a general term applicable to all basalt glass, and to follow Penck [2] and Teall [3] in treating sideromelan as merely a variety of tachylyte.

[1] *Bull. Geol. Soc. Amer.*, XXXIII, p. 783, (1922).
[2] *Zeit. d. d. Geol. Gesellsch.*, XXXI, p. 122, (1879).
[3] 'British Petrography,' p. 137.

The other point of difference maintained by Dr. Peacock is one of conditions of formation, mainly differences of temperature. According to Dr. Peacock some Iceland palagonite has been formed by the action of cold sea-water under the pressure of the head of the overlying water and some has been formed by hot springs (the hot volcanic waters of Bunsen) at atmospheric pressures. In the case of the Indian basalts the 'palagonitisation' is supposed to have resulted from the attack of residual magmatic waters whilst the basalts were cooling through the range of temperature from 374°C (the critical temperature of water) down to at least 200°C. The difference does not appear to me to be one of kind, but merely one of degree, as is illustrated by Iceland, where we have the production of palagonite by both cold water and hot springs. In all these cases, the formation of the ultimate hydrated product has been accompanied by the relative removal of lime, alkalies, alumina, and silica, with relative increase in the amount of iron and magnesia, and with the addition of water. The process is similar and the question is whether the products are the same.

On page 66 of his paper, Dr. Peacock gives an analysis of palagonite-rock. It appears from the text that this rock contains:

	Per cent.
Palagonite [1]	76
Sideromelan	3
Chlorite	14
Zeolites	7
	100

Making rough allowances for the composition of the other materials, it may be deduced that the composition of the palagonite itself is approximately as follows:—

	Per cent.
SiO_2	35
TiO_2	2·5
Al_2O_3	8
Fe_2O_3	13
FeO	0
MgO	7·5
CaO	7
Na_2O	0
K_2O	0
H_2O	27
	100·0

[1] In the restricted sense adopted by Dr. Peacock.

It is now necessary to discuss the composition of chlorophæite, which in my paper on the Bhusawal basalts is shown to be closely related to the substances there designated palagonite.

II.—COMPOSITION OF CHLOROPHÆITE.

The available analyses of chlorophæite are collected in the following table, with the addition in the final column of the analysis of palagonite from Iceland deduced on page 414 :—

Locality.	CHLOROPHÆITE.				PALAGONITE.
	Scuir Mohr, Rum.[1]	Nagpur, India.[2]	Near Edinburgh.[3]	Giants' Causeway.[4]	Iceland.[5]
SiO_2 . .	36·00	35·15	32·95	35·99	35
Al_2O_3 . .	..	1·00	5·40	10·49	8
Fe_2O_3 . .	22·80	21·77	12·37	11·89	13
FeO . .	2·46	2·18	9·18	1·63	0
MnO . .	0·50	0·35	0·33	0·08	..
CaO . .	2·52	2·51	3·05	5·15	7
MgO . .	9·50	5·02	4·75	10·52	7·5
Na_2O . .	tr.	..	1·68	0·76	..
K_2O . .	tr.	..	0·36	0·34	..
H_2O+ . .	7·23 (100°+)	4·98 (110°+)	5·20 (105°+)	9·04 (100°+)	27
H_2O- . .	19·23	27·44	23·90	14·16	
TiO_2 . .	..	..	0·62	..	2·5
Total . .	100·24	100·40	99·79	100·05	100·0
G . . .	(2·02)	1·83—1·84	1·81±	2·278	..
Refractive index	..	1·486±·001	1·498±	..	1·500

[1]Analyst Heddle: *Trans. R. Soc. Edinb.*, XXIX, p. 87 (1879).
[2] Analyst P. C. Roy: *Rec. Geol. Surv. Ind.*, LVIII, p. 127 (1925). Refractive index by W. A. K. Christie.
[3] Analyst W. H. Herdsman: *Min. Mag.*, XX, p. 438 (1925).
[4] Analyst Heddle: *L.c.*, p. 88.
[5] Calculated from analysis by W. H. & F. Herdsman: *Trans. R. Soc. Edinb.*, LV, p. 66 (1926).

The four analyses of chlorophæite have been arranged in order of increasing alumina. A comparison of the Scuir Mohr and Nagpur analyses reveals a striking similarity between these specimens from two widely separated localities. The only noteworthy difference is that the Scuir Mohr mineral contains about 4½ per cent. more MgO and 6 per cent. less total water. The suggestion is that non-aluminous chlorophæite is a definite mineral with a definite chemical composition. The two aluminous chlorophæites form another pair,

though not so closely related, between which the main differences are 5 per cent. more alumina and 6 per cent. more magnesia in the Irish mineral, and $7\frac{1}{2}$ per cent. less ferrous oxide and 6 per cent. less total water, than in the Edinburgh specimen. As a pair the aluminous chlorophæites are distinguished from the non-aluminous chlorophæites by their high alumina and the presence of a small but definite quantity of alkalies, in which soda predominates over potash. If one recalls the direction of change involved in the formation of chlorophæite in a basalt one may suggest that the aluminous chlorophæites are examples in which the removal of alkalies and alumina has not been pushed to a finish. The close similarity between the specific gravity and refractive indices of the Nagpur and Edinburgh specimens shows, however, that the resultant products are physically very closely allied.

On comparing the analysis of Iceland palagonite with those of chlorophæite, it is seen that it also must be regarded as an aluminous chlorophæite. In composition it is very close to the chlorophæite from the Giants' Causeway. The only marked difference is the absence of alkalies. This is due in part only to the fact that in deducing this composition from the analysis of the palagonite-rock the alkalies in the original analysis were allocated to zeolites; for the original analysis shows only 0·35 per cent. of total alkalies. The chemical similarity is in consonance with the almost identical refractive indices of the Iceland palagonite and the aluminous chlorophæite of Edinburgh. It seems very difficult therefore to treat the Iceland palagonite as a different mineral from chlorophæite.

The above analyses may be summarised as follows :—

——	Non-aluminous chlorophæite.	Aluminous chlorophæite.	Iceland palagonite.
SiO_2	35·15—36·00	32·95—35·99	35
R_2O_3	22·77—22·80	17·77—22·38	21
RO	10·06—14·98	17·31—17·38	14·5
R_2O	tr.	2·04— 1·10	. .
H_2O	32·42—26·46	29·10—23·20	27
TiO_2	. . . .	0·62	2·5
Refractive Index . .	1·486 (Nagpur)	1·498 (Edinburgh)	1·500 (Iceland)

Since these analyses when thus studied appear to agree so closely in a general way, it becomes interesting to examine whether they conform to any general chemical formula.

In the following table the five analyses have been reduced to molecular terms with the SiO_2 shown as 20:—

——	Scuir Mohr.	Nagpur.	Edinburgh.	Giants' Causeway.	Iceland.
SiO_2 (+TiO_2) .	20·00	20·00	20·00	20·00	20·00
R_2O_3 . .	4·78	5·01	5·06	5·93	5·19
FeO, MnO, CaO.	2·90 } 10·80	2·75 } 7·02	6·75	3·88	4·07 } 10·17
MgO . .	7·90	4·27	4·25 } 12·11	8·14 } 12·85	6·10
Alkalies . .	..	..	1·11	0·53	..
H_2O+ . .	13·46 } 49·27	9·49 } 61·81	10·36 } 58·31	16·78 } 42·14	.. } 48·83
H_2O— . .	35·81	52·32	47·95	25·36	..

A study of these molecular proportions shows that in the Nagpur analysis the molecular ratios approach closest to the whole numbers. The formula for the Nagpur mineral may be given as follows:—

$$9\tfrac{1}{2}H_2O.7RO.5R_2O_3.20SiO_2+52\tfrac{1}{4}H_2O.$$

This analysis happens also to be that showing the smallest molecular proportion of RO, and therefore will serve as a useful datum line. Bringing the R_2O_3 in each case to 5 by making an adjustment between the Fe_2O_3 and FeO, the 5 analyses correspond to the following molecular formulæ:—

Nagpur	$9\tfrac{1}{2}H_2O.7RO.5R_2O_3.20SiO_2+52\tfrac{1}{4}H_2O.$
Edinburgh . . .	$10\tfrac{1}{4}H_2O.11RO.1R_2O.5R_2O_3.20SiO_2+48H_2O.$
Scuir Mohr . . .	$13\tfrac{1}{2}H_2O.10\tfrac{3}{4}RO.5R_2O_3.20SiO_2+35\tfrac{3}{4}H_2O.$
Iceland	$13\tfrac{1}{2}H_2O.10\tfrac{1}{2}RO.5R_2O_3.20SiO_2+35\tfrac{1}{2}H_2O.$
Giants' Causeway . .	$16\tfrac{3}{4}H_2O.14\tfrac{1}{4}RO.\tfrac{1}{2}R_2O.5R_2O_3.20SiO_2+25\tfrac{1}{4}H_2O.$

For the purposes of this paper and brevity of expression I propose to refer to the water driven off up to 100° to 110°C (different analysts use different temperatures) as *non-molecular water* and that driven off above this temperature as *molecular water*. A study of these formulæ shows that quite closely for every addition of one unit of 'molecular water' there is a decrease of four units of 'non-molecular water'. In the Iceland case, the water has been arbitrarily distributed in the proportions contained in the nearest parallel, the Scuir Mohr analysis.

A comparison of the formulæ allotted to the two extremes of this series—the Nagpur and Giants' Causeway minerals—suggests

the following general formula for the chlorophæites, R_2O when present being regarded as RO: -

$$2\tfrac{1}{2}H_2O.5R_2O_3.20SiO_2+n(RO.H_2O)+(80-4n)H_2O.$$

The first term is suggested by the fact that in both extremes of the series the difference between combined water and RO is $2\frac{1}{2}$; and the final term of $(80-4n)\ H_2O$ by the relationship between combined and additional water already noted.

The values for the above formula with $n=7$, 8, 11, & 14, respectively, are shown in the following table :—

Value of n	—	Compare formulæ on p. 417 for :—	Errors.
7	$9\frac{1}{2}H_2O.7RO.5R_2O_3 20SiO_2+52H_2O$	Nagpur .	$\frac{1}{4}H_2O.$
8	$10\frac{1}{2}H_2O.8RO.5R_2O_3\ 20SiO_2+48H_2O$	Edinburgh	$\frac{1}{4}H_2O,3RO,1R_2O.$
11	$13\frac{1}{2}H_2O.11RO.5R_2O_3.20SiO_2+36H_2O$	{ Scuir Mohr	$\frac{3}{4}RO,\frac{1}{4}H_2O.$
		{ Iceland .	$\frac{1}{2}RO,\frac{1}{2}H_2O.$
14	$16\frac{1}{2}H_2O.14RO.5R_2O_3\ 25SiO_2+24H_2O$	Giants' Causeway.	$\frac{1}{4}H_2O.\frac{1}{4}RO,\frac{1}{2}R_2O,1\frac{1}{4}H_2O.$

The fourth column shows the departures from these ideal formulæ of the actual formulæ referred to in column 3.

The only formula empirically determined that disagrees at all seriously with the above is that of the Edinburgh specimen, which shows 3RO and $1R_2O$ in excess. In both the Edinburgh and Giants' Causeway analyses, the alkalies are in excess of the formula, and it is perhaps doubtful if they enter therein. But obviously there is no basis for discussion of this point or of the meaning of the slight departures in the amounts of RO and H_2O shown in the other analyses. They may all lie within the limits of experimental error.

The closeness with which these five analyses, as also an analysis of neotocite (see page 427), conform to the general formula may be judged from fig. 1. The line AB represents the ratio of 'non-molecular' water to 'molecular' water for values of n from 0 to 20. The spots represent the actual water ratios for the six analyses. The thinner line CD represents the number of units of RO (with R_2O) for the same range of n from 0 to 20. The crosses show the actual values of RO for the six analyses. The only value that falls seriously out of place is that of RO for the Edinburgh chlorophæite. The value of the refractive index is shown where known. The progressive increase with increase of n is illustrated.

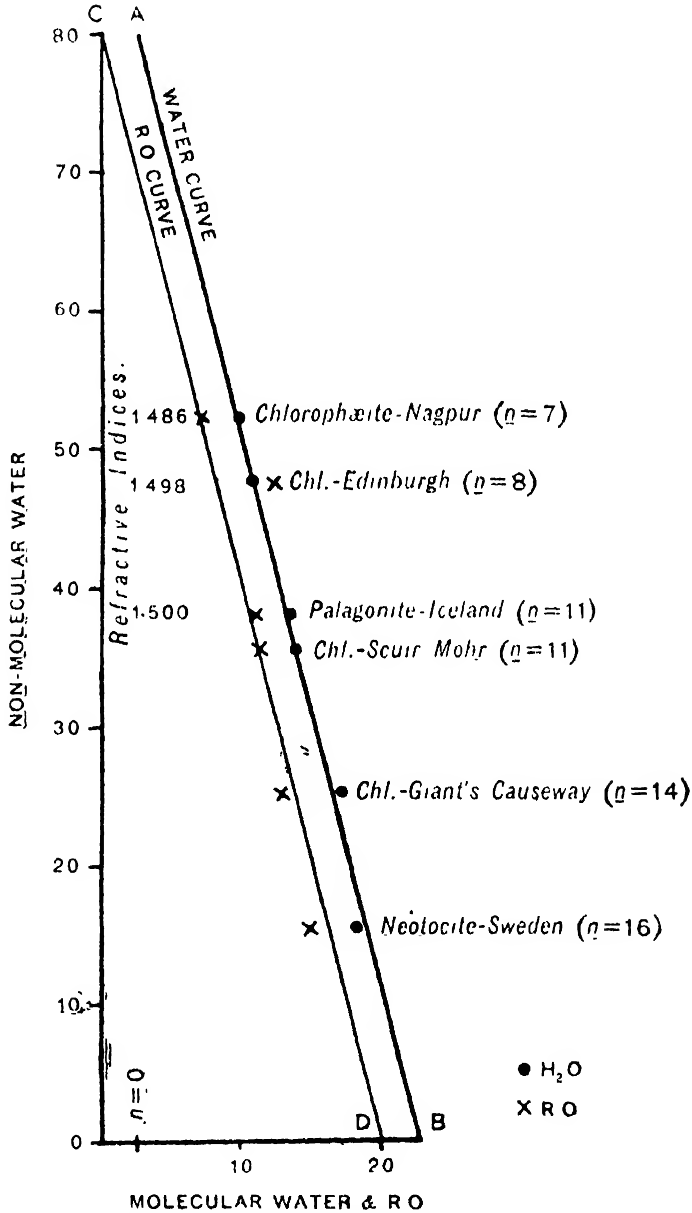


Fig. 1.—Distribution of water in minerals of the chlorophæite series.

III. THE USE OF THE TERM PALAGONITE.

From the preceding section it will be seen that it is difficult to treat the palagonite (*i.e.*, the gel-portion of the palagonite-rock) of Iceland as a different substance from chlorophæite. In petrographical literature the term 'palagonite' seems, however, to have received an application more comprehensive than to a substance with the characters of the palagonite of Iceland. In my paper on the 'Basaltic Lavas in Bhusawal,' I devoted several pages[1] to a discussion of the characters, composition and formation of palagonite and chlorophæite. The following quotation from page 133 may be given here :—

'From the foregoing notes we see that under palagonite have been comprised at least two distinct substances. Treated generally, palagonite may perhaps be regarded as a hydrous glassy substance of variable composition formed partly by hydration of the primary glass and partly at the expense of augite (? again largely hydration) and iron-ore, and with much more difficulty at the expense of felspar (? by replacement). In colour it ranges through orange and brown to brownish green and bright green, and the material of all colours may become 'devitrified' and anisotropic in spherulites and concentric-radiate layers, with in all cases a positive elongation to the fibres. The clear orange and brown varieties, both isotropic and anisotropic, constitute chlorophæite, whilst the anisotropic green form is probably indentical with delessite or celadonite. It is exceedingly difficult to distinguish these two latter minerals one from another when in fine aggregates, but if one may assume the green mineral of the palagonite to be delessite, then the difference between orange palagonite (chlorophæite) and green palagonite (delessite) is very simple. A reference to the analyses given on page 136 will show at once that in most respects these two minerals are chemically very closely allied: the chief difference is that in chlorophæite the iron is mainly in the ferric condition whilst in delessite it is mainly in the ferrous condition. In addition, whilst delessite contains alumina as an essential constituent, the chlorophæite of the original locality is practically devoid of alumina. The chlorophæite of Giants' Causeway, however, yielded 10 per cent. of Al_2O_3. Finally, chlorophæite is more highly hydrous. It appears therefore legitimate to deduce that the formation of one or other of these two minerals is largely a function of degree of oxidation at the time of alteration. As both delessite (30 per cent.) and chlorophæite (36 per cent.) contain a considerably smaller percentage of silica than any of the original substances, primary glass (about 50 per cent.), pyroxene (about 55 per cent.) and labradorite (about 55 per cent.)—except iron-ore, their formation as a secondary product involves the separation of silica. This may, of course, be either removed in solution to be deposited in geodes and vesicles, or it might crystallise out as an additional complementary mineral with

Palagonite in general.

Chemical difference between orange palagonite (chlorophæite) and green palagonite (delessite).

[1] *Rec. Geol. Surv. Ind.*, LVIII, pp. 125-135.

the palagonite. In the case of the green palagonite, where the Al_2O_3 is retained, the surplus silica has often appeared as the enclosed spherulites of chalcedony noted above. But in the case of chlorophæite, as the Al_2O_3 of the original minerals is not always retained, the destination of this constituent appears also to require explanation. The chabazite supplies the obvious answer, for it explains the destination of both surplus Al_2O_3 and SiO_2, which may be assumed to have taken over such alkalies as were available. From this it should follow that chlorophæite is lower in alkalies than delessite. Alkalies cannot, however, be regarded as an essential constituent of either mineral and the published analyses suggest no marked difference in this respect. If therefore the green mineral be delessite it seems necessary to assume that its formation has involved the removal of alkalies in solution. Both chlorophæite and delessite are low in lime: in the former case the destination of this constituent, at least in part, is the accompanying chabazite, but in the formation of delessite lime must also have been removed in solution.'

In this paper it is shown that no distinction can be drawn between chlorophæite and orange or brown palagonite and if the term palagonite is to be restricted to the brown and orange varieties, then it is unnecessary as a mineral term, because the term chlorophæite has priority; but in the form of the name of a process, namely *palagonitisation* it would still find use. If, however, the extended use of the term palagonite be retained, in accordance with which certain green substances also come under this term, then we are giving to the term palagonite a more comprehensive meaning, and, in this form, it will be of more use to science than if restricted to identity with chlorophæite. A study of Penck's elaborate paper 'Ueber Palagonit und Basalttuffe'[1] shows also that in spite of the use of the term *Palagonitfels* by Von Waltershausen the substances from Palagonia, Sicily, Iceland, and elsewhere, to which the term palagonite was originally applied were impure substances, namely rocks, *e.g.* many of the materials analysed by Bunsen[2]. And Dana[3] lists palagonite as—

'A basaltic tufa consisting chiefly of glass lapilli and the products of their alteration. It formerly passed as a mineral species, but properly belongs to petrography.'

It seems clear, therefore, that the term palagonite was originally applied to a less pure substance than that for which the term chlorophæite was proposed. It seems, therefore, that palagonite should be treated rather as a rock name whilst chlorophæite should be treated as the name of a gel-mineral. In this comprehensive sense

[1] *L.c.*, p. 567. 'Es existirt kein Mineral Palagonit'.
[2] *Pogg. Annalen*, LXXXIII, pp. 221-229, (1851).
[3] 'System of Mineralogy', p. 1043, (1911).

palagonite includes hydrated basaltic glass with, in some cases, products of replacement of minerals contained in, or associated with, basaltic glass. Palagonitisation is the process by which these hydrated products are formed. The products of palagonitisation may be either orange, brown, or green. If orange or brown, the substance is chlorophæite; if green, it is probably delessite, but this point has not yet been proved by analytical work. The analysis of palagonite used in these pages for comparison with analyses of chlorophæite is really an analysis of palagonite after removal of the other constituents, which are really a part of the palagonite, i the latter be treated as a rock.

IV.—THE CHLOROPHÆITE SERIES.

The discovery that even a general formula can be applied to a series of specimens of an apparent colloid substance obtained from several diverse localities indicates that chlorophæite cannot be treated as an indefinite mixture, but must be regarded as a definite mineral, the varieties of which have a range of composition conforming to a general formula.

Once the existence is admitted of a series of substances conforming to a general formula, it becomes a matter of curiosity to ascertain whether there are any other minerals either colloid or crystalline that conform to this general formula. To determine this point involves in the first place searching for hydrated minerals in which the ratio $R_2O_3 : SiO_2 = 1 : 4$, *i.e.*, $5 : 20$. It is obvious from inspection of the general formula that any compound with this ratio and with RO from 1 to 20 can be assigned to this series, if the amounts of molecular and non-molecular water be not taken into account. The following is a list of such minerals:—

Value of n.	Name of mineral.	G.	Refractive index.	H_2O divergence from series formula.
0	Montmorillonite	..	1·49—1·51 (1·56)	– 18
	Chloropal	..	..	..
2½	Nontronite	2·50	1·588, 1·590, 1·645	– 50
3	Nontronite	..	..	– 40
5	Phillipsite	2·2	1·48, 1·51, 1·57	—45
	Gismondite	2·27	1·539	– 45
	Laumontite	2·3	1·524	– 47½
	Chabazite	2·1	1·478, 1·480, 1·485	37½
	Gmelinite	2·1, 2·17	1·464, 1·470, 1·481	– 37½
	Analcite	2·25	1·487	– 57½
	Glauconite	2·2—2·8	1·688	– 56
7	Chlorophæite	1·83 - 1·84	1·486	+ ¼
	Graminite	1·87 (at 100°C.)	..	—31
7½	Stilpnomelane	2·85	1·595, 1·685	– 50
8	Chlorophæite	1·81	1·498	– ¼
11	Chlorophæite	2·02	..	– ¼
	Palagonite	..	1·500	– ½
	Minguetite	2·86	..	– 10
12	Bardolite	2·47	..	– 14
14	Chlorophæite	2·278	..	+ 1¼
16	Neotocite	2·6	1·47, 1·54	+ ½
22½	Biotite	2·7—3·1	1·57—1·60	– 12½

The figures in the final column indicate the divergence between the total amount of water present and the total amount required for a mineral conforming to the general formula of the chlorophæite series for the values of n shown in the first column. In the case of the zeolites the water divergence is calculated from the formulæ as given by Dana, but for the other minerals the divergence is calculated from actual analyses, the analyses used being collected in the following table, in which also two of the chlorophæite analyses are included in order to show the position of this mineral with reference to the others :—

Value of *n*	0	1	0	3	5	5	7	7	7½	11	12	14	16	23½
Mineral	$R_2O_3 = Al_2O_3$.	Montmorillonite	$R_2O_3 = Fe_2O_3$.	Nontronite.	Chabazite.	Glauconite.	Chlorophaeite	Granulite.	Stilpnomelane.	Minguetite.	Bardolite.	Chlorophaeite.	Neotocite.	Anomite (biotite.)
Locality		Montmorillon, France.[1]		Nontron, France.[2]	Nidda, Hesse.[3]	Lewes, Sussex.[4]	Nagpur.	Menzenberg, Germany.[5]	North, Wales.[6]	Minguet, France.[7]	Bardo, Poland.[8]	Giant's, Causeway.[9]	Gestrikland. Sweden.[10]	Lake Baikal.[11]
SiO_2 .	37·82	49·40	34·56	44·0	46 35	48·12	35·15	38·3[illegible]	43·74	43·65	38 36	35·99	34·38	40 00
Al_2O_3 .	15·68	19·70	..	3·6	20 52	9·16	1·09	6·87	6·36	5·22	5·54	10 19	1·57	17·28
Fe_2O_3 .	..	0 80	22·89	29·0	..	19 10	21·77	25·46	22·47	18 80	16·59	11·8[illegible]	18·58	0 72
FeO .	..	..	..	..	..	3 47	2·18	2·80	15 74	19·00	4 60	1·63	2·88	4·88
MnO .	..	..	..	..	..	..	0 35	0·67	0·50	..	..	0·03	22·67	..
CaO .	..	1·50	..	..	10·83	0 76	1·5[illegible]	0·56	0·53	0 04	0·73	5·15	..	..
MgO .	..	0·27	..	2·1	..	2·36	5·02	0·75	1·43	3·22	9·41	10·52	2·50	23·91
K_2O	..	1·50	..	..	0·21	7·08	..	1·14	0·75	3·00	4·67	0·34	..	8·57
Na_2O .	..	Tr.	..	..	..	0·22	..	..	..	0·66	0·46	0·76	..	1·47
H_2O+ .	1·41	15·12	1·29	18·7* (80°)	22·09	5·28 (105°)	4·98	23 36	6·36	6 00	7 10 (100°)	9·04	9·30	1·37
H_2O- .	45 03	10·55	41·26	..		4·78	27·44		2·59		12·40	14·16	8·07	..
F . .	..	..	..	1·2 (Clay).	..	..	..	..	..	..	..	..	..	1·57
		98·84	..	98·6	100 00	100·33	100·40	100·00	100·17	100·49	99·89	100·05	99·95	99·77

* Takes up about 12% more H_2O when immersed.
[1] Dana, p. 690, Analysis No. 1.
[2] Dana, p. 701 Analysis, No. 2.
[3] Dana, p. 591· Analysis, No. 1.
[4] Hallimond, *Min. Mag.* XIX, p. 331, Analysis, No. 12.
[5] Dana, p. 701, Analysis, No. 7.
[6] Hallimond, *Min. Mag.*, XX. p. 194, Analysis No. 1.
[7] Lacroix, *Bull. Soc. Franc. Min.*, XXXIII, p. 272.
[8] Morozewicz, *Bull. Soc. Franc. Min.*, XLVII, p. 52.
[9] Dana, p. 662, Analysis No. 2.
[10] Dana, p. 704, Analysis No 4.
[11] Dana, p. 630, Analysis No. 1.

With the exception of the group of zeolites corresponding to $n=5$, and biotite, which, with $n=22\frac{1}{2}$, is just outside the series, the whole of these minerals occur in nature as fibrous, scaly or amorphous minerals, almost invariably in circumstances that show that they have been formed by the alteration of pre-existing minerals, in the presence of abundance of water. From the list on page 423 it will be seen, however, that the only other mineral that actually carries the correct total amount of water required for the chlorophæite series is neotocite (analysis 4 of Dana), and as the distribution into molecular and non-molecular water is also correct, neotocite, as represented by this analysis, may be regarded as a *mangan-chlorophæite.* In addition, glauconite and bardolite have the correct molecular water, but a deficit of non-molecular water.

When I started this search for additional minerals that might be referred to the chlorophæite series, I thought it possible that montmorillonite and chloropal (of which nontronite is treated as a variety by Dana) might prove to be the end members with $n=0$ and $R_2O_3=Al_2O_3$ and Fe_2O_3 respectively. The result is to show that montmorillonite and chloropal contain much too small a quantity of water to be referred to the chlorophæite series, but it may be suggested that each of these minerals at some stage of its formation, which probably was accompanied by progressive dehydration, may have conformed to the series formula.

In the course of consideration of the minerals given in the list on page 423 notes on each were prepared and the formulæ calculated and arranged in accordance with the general formula of the chlorophæite series. But it is considered that it will be of interest to print here only the notes on montmorillonite, chloropal with its variety nontronite, and neotocite.

Montmorillonite ($n=0$, 1).

The formula for $n=0$ is—

$$2\tfrac{1}{2}H_2O.5R_2O_3.20SiO_2+80H_2O.$$

The formula given by Dana is—

$$H_2Al_2Si_4O_{12}+n\text{aq}. \text{ Le Chatelier.}$$

But the water is much less than $80H_2O$, as is shown by the figures in the table on page 424.

The analysis from Dana (by Salvetat) there quoted corresponds to—

$$20\tfrac{1}{2}H_2O.RO.5Al_2O_3.20SiO_2+14\tfrac{1}{4}H_2O.$$

The formula $n=1$ requires $(3\tfrac{1}{2}+76)H_2O$.
The formula adopted by H. Leitmeier[1] is—

$$Al_2O_3.4SiO_2.6H_2O.$$

Montmorillonite is found in abundance in the Central Provinces of India in the joint planes of certain manganese-ore deposits, *e.g.*, Kachi Dhana and Kandri. A specimen from Kachi Dhana gave on analysis figures close to those of the original mineral from Montmorillon, the total water being 26·76 per cent. ($37\tfrac{3}{4}H_2O$ against $34\tfrac{3}{4}H_2O$).

Chloropal. ($n=0$).

Whilst montmorillonite might be regarded as related to the end member of the series with $n=0$ and $R_2O_3=Al_2O_3$, chloropal might perhaps be regarded as related to the end member with $n=0$ and $R_2O_3=Fe_2O_3$. Dana gives the formula of chloropal doubtfully as $H_6Fe_2Si_3O_{12}+2H_2O$. If, however, it belongs to the chloro phæite series the formula should be $2\tfrac{1}{2}H_2O.5Fe_2O_3.20SiO_2+80H_2O$. The compositions required by these two formulæ are as follows:—

——	Dana.	$n=0$.
H_2O	20·9	42·55
Fe_2O_3	37·2	22·89
SiO_2	41·9	34·56

A few of the analyses given in Dana have the ratio $Fe_2O_3 : SiO_2$ approximating to the figures required by Dana's formula, but the majority are closer to the ratio 1 : 4. Usually there are small quantities of protoxides present so that $n=2$ or 3, as in nontronite:

Nontronite ($n=2\tfrac{1}{2}$ to 3).

This mineral is listed by Dana as a variety of chloropal, and is treated by Larsen[2] as identical with chloropal. Analysis 2 of

[1] *Zeitsch. Kryst.*, LV, p. 356, (1915).
[2] *Bull.* No. 679. *U. S. Geol. Surv.*, p. 286. (1921).

Dana has $Fe_2O_3 : SiO_2$ almost exactly$=1:4$; but taking Al_2O_3 into account the ratio is 1 : 3·4. Treating a portion of the Fe_2O_3 as 2FeO, however, the analysis corresponds to :—

$$5\tfrac{1}{2}H_2O.3RO.5R_2O_3.20SiO+22\tfrac{1}{4}H_2O.$$

The last term should be $68H_2O$ for $n=3$. Larsen gives the formula of nontronite as :—

$$(Ca,Mg)O.2Fe_2O_3.8SiO_2.7\pm H_2O.$$

This is equivalent to :—

$$5H_2O.2\tfrac{1}{2}RO.5R_2O_3.20SiO_2+12\tfrac{1}{2}H_2O.$$

This corresponds with $n=2\tfrac{1}{2}$, except that the last term should be $70H_2O$.

Neotocite ($n=16$).

No formula is given for this mineral by Dana, who describes it as a hydrated silicate of manganese and iron, but of very doubtful composition. The proportion of sesquioxides is very variable, and in three analyses a high proportion of Mn_2O_3 is indicated. One analysis (No. 4) corresponds with the following formula :—

$$18H_2O.14\tfrac{3}{4}RO.5R_2O_3.20SiO_2+15\tfrac{1}{2}H_2O.$$

$n=16$ requires—

$$18\tfrac{1}{2}H_2O.16RO.5R_2O_3.20SiO_2+16H_2O.$$

This mineral, therefore, may be regarded as belonging to the chlorophæite series, even the degree of hydration and distribution of water being correct. If this analysis be correct, then neotocite may be regarded as a *mangan-chlorophæite* with MnO in place of MgO, etc., and with less water owing to its position in the series. The specific gravity (2·94) of neotocite is considerably higher than that of chlorophæite (1·81 to 2·28), but the refractive indices are closely similar :—

Neotocite (Larsen)	1·47 —1·54
Chlorophæite [1]	1·480—1·500

Larsen (*L.c.*, p. 115) remarks that the name neotocite should be confined to the amorphous mineral that has approximately the composition of bementite ($MnO.SiO_2.nH_2O$). If, however, as the

[1] The refractive index of the chlorophæite of Bhusawal ranges up to a figure slightly above that of Canada Balsam, *i.e.*, to over 1·544. *L.c.*, pp. 131, 151.

analyses show, neotocite contains considerable amounts of sesquioxides, then the foregoing treatment seems more suitable.

Summarising the above we may say that chlorophæite, palagonite, and neotocite, have the correct molecular and non-molecular water to be assigned to the series represented by the formula :—

$$2\tfrac{1}{2}RO.5R_2O_3.20SiO_2+n(RO,H_2O)+(80-4n)H_2O.$$

These minerals are all secondary colloid minerals, formed as the result of hydration of pre-existing minerals, and possessing refractive indices ranging from 1·47 to 1·54.

In addition, glauconite and bardolite correspond with the series formula except for a deficit of non-molecular water.

In nontronite and graminite (both varieties of chloropal) the molecular and non-molecular water have not been determined separately, except that nontronite may absorb water up to a total of 30 per cent. which is reduced to 18·7 per cent. at 80°C.[1] All that one can say safely of these two minerals is that there is a deficit of total water.

In montmorillonite, although the total water is too small, yet the combined water is too high for the formula.

This leaves only the zeolites, stilpnomelane, minguetite and biotite, which are definitely crystalline minerals. Although zeolites lose their water gradually on heating yet their maximum water is well below that required by the formula. Perhaps it may be suggested, however, that should they ever be found in colloid form they might carry water approximating to the formula.

It may be suspected from their mode of occurrence and microscopic appearance that did they occur in crystal form most members of this 1 : 4 series would prove to be micaceous in structure.

V.—SUMMARY.

1. Chlorophæite is a gel-mineral of variable composition, but the variations take place within the limits of a general formula, which is :—

$$2\tfrac{1}{2}H_2O.5R_2O_3.20SiO_2+n(RO.H_2O)+(80-4n)H_2O.$$

2. Four analyses of chlorophæite from Nagpur, Edinburgh, Scuir Mohr, and the Giant's Causeway, respectively, correspond to expressions of this formula with $n=7$, 8, 11 and 14.

[1] Berthier, *An. Ch. Phys.*, XXXVI, p. 24, (1827).

3. In so far as the data are available the specific gravity and refractive indices increase with the value of n.

4. The gel-mineral of the Iceland palagonite-rock described by Dr. Peacock is deduced to have a composition that brings it into the chlorophæite series with $n=11$. The refractive index of this palagonite falls into the correct place.

5. The term chlorophæite (Macculloch, 1825) has priority over palagonite (Von Waltershausen, 1846).

6. It is deduced, therefore, that the term palagonite should not be employed as a mineral-name and that the practice of Penck and Dana should be followed in accordance with which palagonite is regarded as a rock. When the rock contains no extraneous substances then palagonite equals chlorophæite-rock.

7. The basalt-glass known as sideromelan, from which some palagonite has been formed by modification and hydration, should be regarded as only a variety of tachylyte.

8. Used to describe certain secondary substances, but without the precision of a mineral name the term palagonite has been extended to comprise two varieties (1) orange and brown, and (2) green. The orange and brown palagonite when clarified from other substances is identical with chlorophæite. The green variety has not been studied but may prove, when free from other substances, to be identical with or related to delessite.

9. It is recommended that the term palagonitisation should be used to designate the process of hydration with accompanying chemical composition by which palagonite of both kinds is formed.

10. A consideration of analyses and properties of other minerals shows that at least one analysis of neotocite conforms to the chlorophæite general formula ($n=16$). This mineral may be regarded as a mangan-chlorophæite.

11. In addition to chlorophæite, palagonite and neotocite, which all have the correct distribution of 'molecular' and 'non-molecular' water to be referred to the chlorophæite general formula, there are several other minerals that conform to the series, except that the water content is deficient. These minerals range from montmorillonite and perhaps chloropal with ($n=0$) at one end of the series, through certain zeolites, glauconite, chlorophæite and various micaceous minerals to biotite at the other end ($n=22\frac{1}{2}$). The tendency is for all the hydrous minerals, excepting the zeolites,

with a ratio of $R_2O_3 : SiO_2 = 1 : 4$ to be, when not amorphous, either fibrous or micaceous. The majority of them are secondary minerals.

12. An examination of the general formula of chlorophæite shows that for every increase of one unit of 'molecular' water (water driven off above 100°–110°C), there is a decrease of four units of 'non-molecular' water (water driven off below 110°C). No explanation of this curious fact is offered, and it will be interesting to see whether future work on the chlorophæite series supports this relationship as expressed in the general formula.

MISCELLANEOUS NOTES.

Barytes from the Anantapur district, Madras.

Barytes occurs in the reserved forest near Nerijamupalle (14°32′30″ 78°1′) in the Anantapur district of the Madras Presidency. It occurs as veins in Vaimpalli slates and limestones which form part of the Papaghni series of the Cuddapah system. The outcrop of the largest vein is from 3 to 11 feet wide and it has been followed for more than half a mile along its strike, N. 110° E.; three other veins crop out close to the above vein, two of which strike respectively N. 125° E. and N. 110° E.

Another outcrop occurs in the Daditota reserved forest, 1½ miles north of the chief Nerijamupalle vein, and this also bears N. 110° E.

A representative set of specimens has been collected from both localities (M. 940 A.—Q. and M. 941 A.—D.). The average specific gravity of the Nerijamupalle barytes is approximately 4·4 and the colour, though generally white, varies to light green and a faint pink. A microscopic section (17574) of the vein material bordering the main vein (36/46) shows an argillaceous limestone with barytes, calcite, a little quartz and some chalcopyrite.

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A. K. DEY.

Barytes in Orchha State.

According to Mr. M. K. Ray, Consulting Geologist, barytes has recently been found within the limits of the village of Khura (now called Surajpura; 24° 43′ 30″ : 79° 10′ 30″), which is 2 miles south-south-east of Deorda and forty miles from the nearest railway station, Man Ranipur (Great Indian Peninsular Railway).

The barytes occurs west of the village by the side of a hill called Chakrada. Mr. Ray, who has examined the deposit, states it is associated with about equal proportions of quartz in a vein in Bundelkhand gneiss and is also found in the adjoining rock. A little copper pyrites occurs with the barytes, but, as far as Mr. Ray could make out from a surface examination, there is insufficient copper ore for the vein to be worked as a supply of copper ore. No lead ore was found.

The vein strikes approximately N.W.-S.E. and it can be traced for about a quarter of a mile. This direction is that of the general strike of the basic rocks intruding the crystallines, but the usual strike of the quartz

veins is from N.N.E.-S.S.W. to N.-S. A little prospecting work has exposed a width of about eight feet of vein without reaching the walls. The estimated cost of transport to Man Ranipur is between Rs. 10 and Rs. 15 per ton.

The barytes found upon the surface is mostly brownish-white in colour, but the quality improves even at a depth of but two to three feet. A specimen (M. 949) was found to have a specific gravity of 4·395.

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